D3.3 Validation report of reduced renovation cost and time

Deliverable Report D3.3

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P2ENDURE

Plug-and-Play product and process innovation for Energy-efficient building deep renovation

This research project has received funding from the European Union's Programme H2020-EE-2016-PPP under Grant Agreement no 723391.

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Colophon

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Publishable executive summary

The objective of WP3 Performance Validation and optimisation is to provide tools and methodologies to control, guarantee and verify the expected performance in terms of energy, environmental impact, Indoor Environmental Quality (IEQ), time and cost efficiency. This report summarizes how the P2ENDURE contributes to achieve at least 15% cost saving and 50% time saving in installation works. This report also outlines how the P2ENDURE technical solutions and methods affect the duration of the overall renovation process. In order to convincingly present benefits of the project, cost and time reduction assessment is performed on selected demonstration sites: Enschede demo site (NL), Gdynia demo site (PL) and Warsaw demo site (PL). Analysis of time efficiency is made through the comparison of two renovation scenarios: 1) P2ENDURE technologies and approach and 2) traditional renovation that would be applied if the P2ENDURE renovation would not take place.

List of acronyms and abbreviations

BIM:	Building Information Model
BEM:	Building Energy Model
CAPEX/OPEX:	Capital / Operational Expenditure
EE:	Energy efficiency
HVAC:	Heating, Ventilation, and Air Conditioning
MEP:	Mechanical Engineering and Plumbing
IDRP:	Innovative deep renovation product
IEQ:	Indoor Environmental Quality
LCC:	Life-cycle costs
LCCA:	Life-cycle cost analysis
MCA:	Multi-criteria analysis
MYMP:	Multi-year maintenance plan
NPV:	Net Present Value
PnP:	Plug-and-Play
R&D:	Research & Development
RoI:	Return on Investment
TRL:	Technology readiness level
IEQ:	Indoor Environmental Quality
EPS:	Expanded Polystyrene
XPS:	Extruded Polystyrene

Contents

1. Introduction

In order to accelerate the interventions of deep renovation, there is a need for innovative building components and the change of renovation process. Therefore, P2ENDURE wants to provide evidence of benefits achievable by PnP systems for deep renovation of building envelope and technical systems, applicable to a wide range of building typologies. The project introduces also the 4M modular process that will successfully streamline renovation process. The 4M stands for: Mapping, Modelling, Making and Monitoring. The process is described in detail in the deliverable *D2.1 4M process roadmap and implementation guidelines*. P2ENDURE proposes a set of innovative technologies and solutions to support and optimize the overall renovation process, from mapping to monitoring:

- PnP prefabricated envelope components: e.g. Multifunctional panels, smart windows, rooftop retrofit module (described in deliverable D1.1),
- PnP technical systems: e.g. PnP Heating, Ventilation, and Air Conditioning (HVAC) systems, modular bathroom module, smart connectors (described in deliverable D1.3),
- On-site 3D technologies: e.g. 3D scanning, 3D printing/robotics, Comfort Eye (described in deliverable D1.5).

Those innovative technologies and solutions as well as new approach to renovation process will lead to achieve at least **60% of energy saving after deep renovation along with 15% cost saving, 50% time saving, improved IEQ and reduced disturbance for the occupants**. The goal is also to fulfill 3 years payback time with application of P2ENDURe systems and methodologies. The P2Endure approach is applicable for buildings transformation, non-functioning or sub-optimal public and historic buildings into dwellings, and renovation without transformation.

Performance indicators for assessment of cost and time efficiency will be verified **on selected real demonstration sites of P2ENDURE project**. This report focuses on proving three indicators:

1) **Life Cycle Cost (LCC) that is 15% less than the traditional comparative cost of deep renovation**
2) **Payback time for P2ENDURE approach allows to achieve <3 years**
3) **Decrease of the installation time by 50% in comparison with available renovation solutions and decrease of the overall renovation time**

The expected key benefits of P2ENDURE technologies and solutions that have impact on reduction of renovation process duration and cost savings are:

- **Faster development of building documentation** with the use of 3D scanning. This is especially important for the old buildings that have only not actual paper documentation.
- **Integration of PnP components and on-site technologies with BIM** and moving forward from traditional 2D designing to integrated BIM designing
- **Better and more accurate design in terms conflict, interference and collision detection**. Due to the fact that 3D model contains building mode with building components and required systems (ventilation, electric system, sewage system, lightning, etc.), all potential conflict and collisions can be visually detected during the design stage and not during the construction process. This process can be helpful for instance for verification of correct tracing of pipes and check if there is no intersection with walls, beams or other ducts. Detection of errors during construction process provokes many delays and cost increase.
- **More efficient and faster renovation works thanks to prefabrication and off-site manufacturing**. Because of prefabrication it is easier to plan the assembly works and delivery of various building components can be better scheduled. Also use of light-weight components (e.g. rooftop retrofit module) reduces the need for heavy machinery on-site.
- **Lower need for skilled blue collar workers** due to the installation on-site already prefabricated building components.

The following demonstration cases have been chosen for validating the performance indicators: installation time of the PnP solutions, duration of the full renovation process as well as the preliminary implementation of LCC analysis in P2ENDURE:

Project	Type of building	Geo cluster	Validated performance indicator
1. Enschede (NL)	Students resident hall & hotel - vacant building with transformation	Western Europe	Installation time & duration of the full renovation process (incl. installation time)
2. Gdynia (PL)	Kindergarten – deep renovation without transformation	Central Europe	LCC & duration of the full renovation process (incl. installation time)
3. Warsaw (PL)	Nursery – deep renovation without transformation	Central Europe	LCC & duration of the full renovation process (incl. installation time)
4. Genoa (IT)	Kindergarten - deep renovation without transformation	Mediterranean	LCC
5. Tilburg (NL)	Temporary housing - deep renovation without transformation	Western Europe	LCC
6. Firenze (IT)	Housing & multifunctional common space - vacant building with transformation	Mediterranean	LCC

2. LCC methodology and tool

Across Europe there is a real and urgent demand for deep renovation of existing building stock and transformation of vacant, obsolete or sub-optimal public buildings into dwellings. However, there are number of barriers that must be overcome in scaling up energy efficiency (EE) in buildings. The barriers include the high costs of innovative technology and lack of knowledge and know-how on energy efficiency measures and the benefits of efficiency improvements, including possible Return on Investment (RoI) after renovation. Simple payback time is a quick mean of evaluating the financial attractiveness of EE measures [1].

The Directive 2014/24/EU on public procurement [2] gives a bigger importance to LCC in the process of tenders awarding. New contract award criteria have been introduced in Article 67: "The most economically advantageous tender from the point of view of the contracting authority shall be identified on the basis of the price or cost, using a cost-effectiveness approach, such as life cycle costing [...]" [3]. Through new R&D projects, the European Commission encourages and facilitates the wide use of LCC by making relevant tools and approaches available.

In P2ENDURE a methodology and a tool for Life-Cycle Costs (LCC) analysis are further developed for deep renovation of buildings and tested on the real renovation projects.

Based on the gathered data and preliminary cost analyses, the proposed P2ENDURE renovation process results in cost reduction of at least 15% by:

- The application of Plug-and-Play (PnP) prefab components (**-5%**): depending on the component the production and installation of the innovative solutions is still often more expensive than implementation of traditional components (with few exceptions, for example in the demonstration case in Tilburg, the Netherlands installation of the PnP bathroom units is much cheaper than integration of new bathrooms with traditional methods). However, the LCCA clearly show the benefits of implementation of innovative technologies in long-term planning; the operational costs of a building are much lower after performing deep renovation in comparison with traditional renovation or maintenance only and the Return on Investment (RoI) can be achieved after 6-8 years depending on a project.
- The application of 3D printing on-site: the 3D printing technology is applicable only for specific renovation projects; in P2ENDURE it will be demonstrated on the Korsløkken demonstration case in Denmark. It has been estimated that due to shorter time of renovation, less materials used (no scaffolding needed) and less labour (only two people

are needed to operate the robot) the costs of the renovation could be reduced even by 20%.

- BIM-based renovation process (**+5%**): BIM facilitates achievement of the goal to improve energy-efficiency in buildings in a shorter time, against reduced costs, with a better quality, and for a significantly higher performance. A recent investigation in the Netherlands [5] has proven the cost reduction based on the current BIM techniques.
- The application of the temporary local renovation factory concept at district level (**+5%**) to improve collaboration between involved stakeholders and create a resilient building process. This results in decreased number of building errors and reduced building costs and time by easier integration of prefabricated components, on-site renovation of existing building elements, improved logistics – reduced transportation to a distant factories, and in-kind involvement of local communities / inhabitants.
- Implementation of the P2ENDURE solutions and methods on a district and regional scale is not yet proven at this stage of the project. In the chapter 4 of this report, time reduction of district-scale renovation is indicated what is directly related to significant reduction of the renovation costs.
- Reduction of construction failure costs (**+10%**): buildings in Europe typically consume two to five times more energy than predicted at the design stage [6, 7]; there is extensive evidence to suggest that buildings usually do not perform as well as predicted. The H2020 project INSITER proves that the use of BIM in design and construction stage can significantly reduce the construction errors and building's energy performance gaps.

Based on the first analyses and results of the demonstration cases and proven data from other projects and studies, the P2ENDURE objective of reducing the costs of building renovation by at least **15%** in comparison with typical renovation (i.e. a renovation that meets current minimum requirements of existing building regulations) can be easily met. These estimations are approximate as the data on the whole renovation process is not yet available at this stage of the project.

The following chapters explain methodology and achieved results of the LCCA of the P2ENDURE demonstration cases showing possible long-term cost savings related to improved building performance and reduced maintenance costs after performing deep renovation with the proposed innovative technologies.

2.1 Methodology

Life-cycle cost analysis (LCCA) is a process of evaluating the economic performance of a building over its entire life [8]. It is also a good method to determine the most cost-effective design strategy among different competing alternatives. With a LCCA tool we can estimate the total resulting costs of a building, from initial construction / renovation through operation and maintenance. By comparing the life-cycle costs (LCC) of various design configurations, we can explore trade-offs between low initial costs and long-term cost savings, identifying the most efficient renovation and maintenance strategy for a given function, and estimate the Return on Investment (RoI) of implemented technologies and general costs of renovation [8].

The purposes for which LCC may be employed can be divided into two broad categories [9]:

- As an absolute analysis to support the processes of planning, budgeting and contracting for investment in constructed assets;
- As a comparative analysis to undertake robust financial option appraisals, for example in relation to potential acquisition of assets, design approaches or alternative technologies.

To understand the impact of the P2ENDURE solutions and design strategies a business case is prepared. A business case describes the reasoning for initiating a renovation project and the effects on profitability due to changes in costs and benefits over a period of time. The Return on Investment (reflecting the relation between the costs and the benefits) and the payback period (the period of time needed for the total benefits to exceed the total costs) are important parameters for the decision to initiate a renovation project.

In P2ENDURE LCCA of the following strategies have been compared:

- Maintenance plan without renovation
- Renovation with tradition renovation techniques
- Renovation with P2ENDURE innovative technologies

The benefits following traditional renovation and deep renovation when using innovative solutions are compared with the consequences of maintaining the current situation, when no actions are planned. It was estimated that over 30 years of a building's life, the present value of maintenance, operations, and utility costs can be nearly as great as the initial projects costs [8]. The aim of performing the LCCA is to provide an evidence of long-term cost effectiveness of performing deep renovation by using innovative energy-efficient technologies.

The business case is calculated for a period of 25 years, as this period is seen as representative for the evaluation of costs and revenues and therefore for decision making. Nevertheless, the calculation period can be easily changed according to the needs.

An inflation percentage and an Income Index (in case of receiving an income) of 2% are used in the LCC calculation. In order to make the costs and benefits comparable for this period also the Net Present Value (NPV – the difference between the present value of cash inflows and the present value of cash outflows over a period of time [W1]) is calculated, based on an interest rate of 3%. These values can be adjusted depending on the current or predicted situation.

For the comparison of the two abovementioned renovation strategies the direct costs and benefits related to investments in renovation are taken into account. An example of the direct costs and benefits are the costs of new windows implementation and the related impact on the reduction of energy and maintenance costs.
Secondary effects, for example decreased absenteeism or increased productivity of employees, are often hard to monetize and the relation with the investment is difficult to prove. They can contribute as additional argumentation for the value case of the customer(s).However, for LCCA in P2ENDURE, these costs as well as management costs are not taken into account in order to check the direct impact of implementation of the P2ENDURE solutions and to prove that they are financially beneficial in a short period of time when only looking at direct costs and benefits.

The expenses, which are part of the P2ENDURE LCC analysis, are divided into two categories:

- Capital expenses (CAPEX), consisting of:
    - Renovation costs per m^2 envelope (e.g. façade panels)
    - Renovation costs per unit (e.g. number of windows)
    - Other costs (e.g. costs of transportation, disposal and removal)
- Operational expenses (OPEX), consisting of:
    - Current maintenance (building-related running costs)
    - Expected additional maintenance after renovation
    - Energy consumption (e.g. costs of heating, electricity)
    - Other operational costs (e.g. costs of water)

The Operational and Maintenance costs are directly impacted by the design (different design strategies will directly influence the operational costs of the building after renovation).

Moreover, they can be taken into LCC decision making on the basis of already early design decision regarding m^2, layers or other early design parameters.

As stated before, the Return on Investment (RoI) and the payback period are important parameters for the decision to initiate a renovation project. The RoI reflects the relation between the costs and the benefits. It measures the gain or loss generated on an investment relative to the amount of money invested [W2]. Therefore, the total benefits are compared with the total costs related to the renovation project, in this case over 25 years.
To calculate the RoI, the benefit (or return) of an investment is divided by the cost of the investment. The result is expressed as a percentage or a ratio [W1].

The RoI formula:
*RoI = [Net Profit / Costs of Investment] * 100%*
where
Net Profit = Total Revenue (gains from investment) – Total Expenses (costs of investment)

The payback period of an investment is the period of time needed for the total benefits to exceed the total costs.
Total costs or benefits are the sum of costs or benefits per year. Total costs or benefits are also referred to as the cumulative figure of costs or benefits.

The Operational and Maintenance expenses have a large impact on LCC as every square meter has to be maintained during the building's entire life cycle. Moreover, trade-offs in decisions regarding refurbishment designs can be taken into account. For example, a relatively old building generally has higher operational and maintenance expenses due to lack of insulation or old installation with a lower efficiency. Such building is less energy efficient and requires more maintenance than a refurbished or a new building. However, the refurbished or new buildings may have additional operational costs related to higher indoor comfort and generally improved building smartness that need to be taken into consideration for the LCCA, e.g. air-conditioning, which is not installed in most of the older buildings.

At more detailed level, different lifecycles of solutions can help to decide between solutions that have the same function (e.g. a window) but carry different product specifications (e.g. wooden window frame vs. aluminium window frame). In terms of LCC, while the expected life cycle for a wooden window frame may be longer (30+ years) than for an aluminium frame (20-30 years), a wooden window frame requires more maintenance, like painting every 5 -7 years, while the aluminium frame does not need to be maintained almost at all. The building owner could choose to select an aluminium frame, which may be slightly more expensive as an investment but, ensuring that over the life-cycle of the building, the window does not need to be maintained every 5 years, what is beneficial in terms of life-cycle costs.

In conclusion, the LCCA points to solutions that are environmentally and financially desirable. Not always the most cost-effective solutions are the most environmentally ideal choices, e.g. a building system may consume very little energy but it costs more to maintain than it saves in energy costs [1]. The benefit of the LCCA tool is that building managers, who face major renovation work, are provided with a clear comparison between different renovation alternatives so they can choose the best design option that results in efficient use of energy and water and in long-term cost savings.

2.2 Tool

A tool for life-cycle cost analyses (LCCA) can be used for an estimation of total costs of an individual building or building stock over certain period of time, including evaluation of different building renovation / transformation design alternatives. It can also serve as a modern procurement tool evaluating the most economic advantageous offer. In P2ENDURE, the life-cycle cost (LCC) analyses are performed by the RE Suite software tool for LCC and asset management, which was developed by DEMO Consultants within the project. The tool enables an assessment of quality and costs of buildings and building components in order to assert control over the real estate asset over time. The RE Suite tool for LCC is accessible for the project partners. Upon request the access can be granted and log-in credentials provided. The tool is described in the D2.4 deliverable report in more details.

Based on the information achieved from a condition assessment and renovation design proposals, capital and operational expenses of a building can be calculated. The deliverable report D2.3 explains the methodology for building condition assessment with the RE Suite tool.

Currently RE Asset Management provides cost estimation of properties maintenance based on Dutch standards. Cost analysis is based on ballpark figures and adapted to specific countries by using index for that country [W3]. In P2ENDURE the analysis will be performed for deep renovation of the demonstration cases in the Netherlands, Italy, and Poland; the index will be adjusted accordingly by choosing the country of the demonstration case in the object information area.

The LCC analyses can be performed for two situations:

- As-Built situation before renovation: data provided from the mobile inspection tool (D2.3) and energy bills / energy audits
- After renovation: data on building components provided by the project partners and stakeholders responsible for the innovative solutions and the partners developing renovation designs of the demonstration cases; data on energy savings of different renovation strategies provided from energy analysis (for more details on the methodology and tools for energy analysis check the D3.1 report)

The essence of the workflow in the P2ENDURE RE Suite software tools can be described as follows:

- The end-user attains an overview of the state of a real estate object through condition assessment, generates a multi-year maintenance plan (MYMP) to define activities needed to maintain the object, and as a consequence, gains insight into the financial consequences of those activities.
- The MYMP is used in combination with other financial data, such as renovation expenditures and expected income, to come to an LCC analysis. This is done for three alternatives: maintain-only, traditional renovation and P2ENDURE deep renovation.
- These three alternatives are then compared on financial, quality, energy and time KPI's to come to an informed decision of the best strategy. The vehicle to visualize this is a multi-criteria analysis (MCA).

These three steps in the workflow are captured in the following RE Suite applications:

- RE Maintenance: Condition assessment and MYMP
- RE Asset Management: LCC analysis
- RE Dashboard: MCA

Deliverable reports D2.3 (mobile inspection tool) and D2.4 (tool for energy monitoring, LCC and asset management) provide detailed descriptions of the abovementioned tools and their technical and functional requirements.

Data required for LCC calculations:

Overall condition	**Unit**
Period for LCC calculations	Year
Interest rate, period and frequency of instalments	%/year
Inflation rate	%/year
Surface / envelope area affected	m^2

Investment costs	
Investment items / entities	EUR, EUR/ m^2
Investment subsidies	EUR
Running operational, maintenance and management	
Management and maintenance costs per year	EUR/ m^2
Rental costs	EUR/year
Energy costs	
District heating costs	EUR/kWh
Hot water costs	EUR/kWh
Electricity costs	EUR/kWh
Energy consumption - district heating	kWh/year
Energy consumption - hot water	kWh/year
Energy consumption - electricity	kWh/year
Revenue	
Costs of renting space to third parties, subsidies	EUR/year

It is not necessary to provide data to all the listed categories for the LCC analysis to be carried out. However, the more information submitted, the more reliable and comprehensive the results of the calculation become. In P2ENDURE the focus is put on the costs and benefits that differ between the renovation alternatives, e.g. the costs of renovation or energy conception. By using these reference costs as a starting point for each renovation measure, the tool can provide analyses that will facilitate the design with the impact of various parameters on the end result.

Revenue can be taken into consideration for commercial buildings. The results of the LCC analysis of the costs and savings related to the renovation and, because of it, improvements of technical condition and indoor comfort can influence possible increase in revenue what is an important factor in asset management.

Design of the tool

From a design standpoint, the purpose of the LCC-tool is fourfold. Firstly, it must allow user input into the dataset of costs and incomes, separated over a number of categories. Secondly, it must extend the dataset with calculated and aggregated supplemental values important for the decision making process. Thirdly, the dataset result must be presented in a logical and comprehensive manner, with various levels of detail depending on the target group. Finally, it must allow a fast iterative process of making minute changes and seeing immediate consequences on the greater whole.

The RE Suite LCC-tool is of a modular nature, separating the calculation logic and data storage from the presentation layer through a Model-View-ViewModel (MVVM) approach (Figure 1).

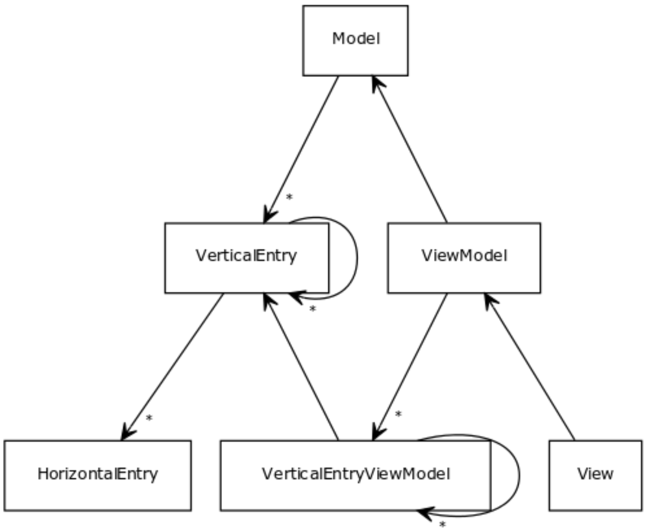


Figure 1: Modularity of the RE Suite LCC-tool.

The right leg of the schematic triangle represents the separation of logic in the Model and presentation in the View, connected through an intermediary in the form of the ViewModel.

The left leg of the triangle represents the decomposition of the model into an object hierarchy: a model consists of a number of vertical entries representing categories. A recursive definition allows vertical entries to contain sub-categories and so on. Finally, leaf vertical entries may contain horizontal entries, representing tabular rows.

The arrows in the above scheme denote dependency relations. It is important to note that all dependencies point from right to left. This means that a view requires a ViewModel and a model to make sense, but the left leg can exist independently of the others. Horizontal entries are the minimal components on the bottom left. They are also the only entity that contains non-volatile data such as user input. Thus, it is only the horizontal entries that require storage to reconstruct the rest of the model.

The model is a digital representation of the life-cycle-cost analysis. It parses input, calculates aggregate values and is responsible for data storage. As a stand-alone component, it can be approached by external entities only interested in the data and/or calculations as opposed the visualisation. The RE Maintenance and RE Dashboard applications are two such examples.

Calculation

There are three phases to a cash-flow calculation.

The first phase, or left-to-right phase, is a projection of current or expected costs and incomes, spread out as transactions over future periods of time. Important factors to consider are:

- Spread. The future spread of costs and incomes is of a variable, yet periodic nature. Some costs may only come into play in 10 years, but reoccur yearly thereafter. Others may instead start immediately and repeat every three years until the fifteen year mark, at which point they stop.
- Nature of initial costs. Some transactions may be defined per interval, others in total, yet others again per unit of measurement such as cost per surface area.
- Inflation. The current cost associated with an object will have increased in the future. As such, an inflation estimate must be applied for each period of time the cost is further removed from the present.
- Income Index. To compensate for inflation, income is also subject to change over time. Like interest is for cost, the prospective income index is cumulatively applied for an estimate of future revenues.

The second phase, or right-to-left phase, is an aggregation of future expenditures with respect to their present value. Important factors to consider are:

- Interest. A monetary sum set aside for future use will grow. Money set aside for an expense in many years will grow more than a deposit soon spent. Thus, the sum of future expenses and incomes, known as the nominal total, is not a representative basis for comparison of this entry with others. Compound interest must be subtracted to arrive at a net present value.

The third phase, or top-down phase, is a summation of values. Important factors to consider are:

- Nature of entry. Expenses must be subtracted from incomes to arrive at a net summation.
- Category subtotals. To gain insight into the nature of life cycle costs on various level of detail the transactions are grouped into categories.
- Cumulative summation. The vertical summation details yearly results and an overall total, but gives no insight into the balance over time. A cumulative summation over the yearly totals does, clearly illustrating the break-even point, as well as the return on investment per year.

Operation

Upon initialisation, the model creates an in-memory representation of the full LCC in the form of an object-oriented tree structure with dependency relations between values. When complete, the database is queried for any previously stored datasets and retrieves and integrates them if present. At this point the model is ready for interaction.

Upon querying by an external party, the model checks if the requested value is presently available. Only if this is not the case is a calculation performed. This recursive process, where values query other values and intelligently remember the results of prior calculations keeps the number of calculations to a minimum. If a value is changed this dependency tree is traversed in reverse, marking each dependent as invalid, but postponing actual recalculation until required.

Upon request, the model collects the totality of input values and submits them to the database for storage. Because of their volatility, nature and to keep file size small aggregated and calculated values are not stored.

To facilitate exchange of data between the presentation layer (view) and the business logic layer (model), a ViewModel acts as a translator. The hierarchical object-oriented data structure within the model is translated into a more tabular format for easy visualisation. The ViewModel also detects changes and is responsible for partial updates of either party.

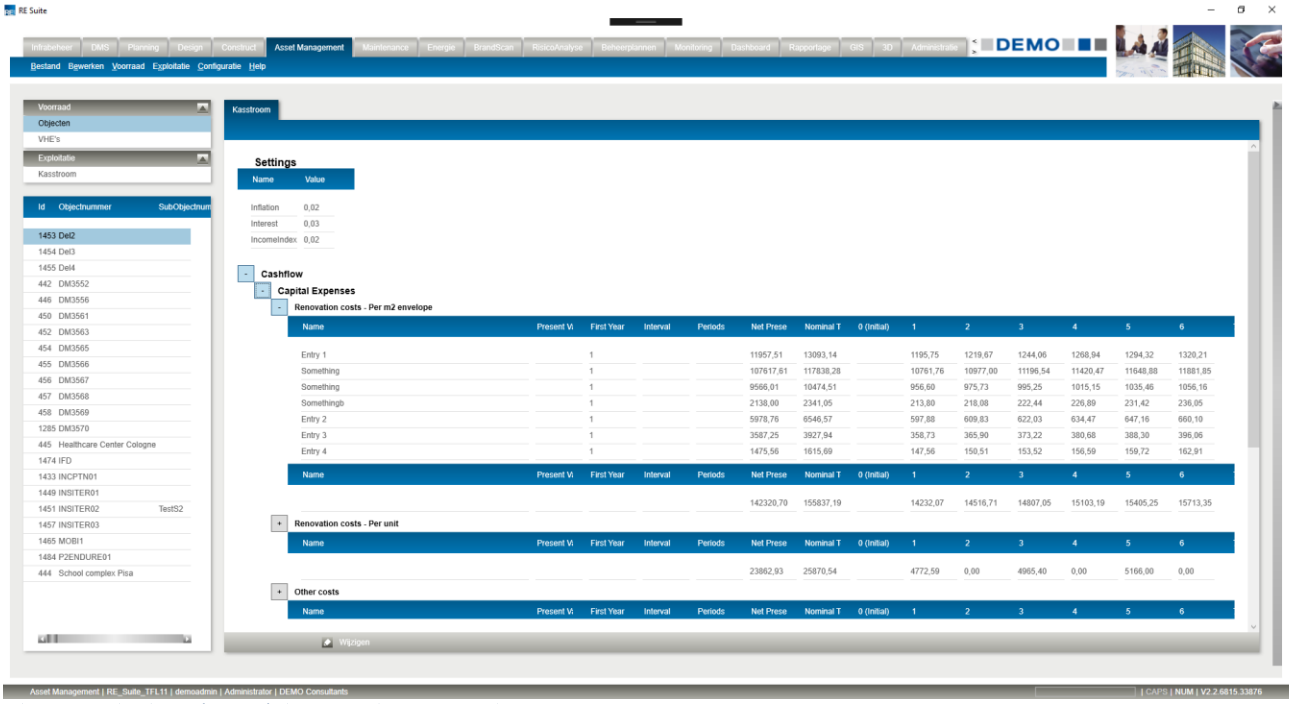


Figure 2: The interface of the RE Suite LCC-tool

Visualisation

The graphical user interface connects with a model through the ViewModel upon initialisation. It produces a visual representation of the model's structure, mapping category hierarchies onto trees of tables and individual values onto table cells. The inflation, interest and income index parameters are displayed separately.

Major adjustments to the visual structure are possible by collapsing and expanding individual sections of the tree, hiding the contents but for a single row displaying the aggregated total.

This serves the different desires of different target groups. For example, an investor only interested in the bottom line can collapse the model to show exactly that without distractions.

Each category may differ in structure from the others. The timespan of costs may be defined in total or per year. The costs themselves can also be defined in different ways:

- per unit of measurement, such as m2,
- per item with specification on the amount, such as 13 windows,
- as an expected in-/decrease with respect to a base amount, such as 25% expected savings on current cost directly.

By setting first year, interval and timespan length parameters a periodic occurrence of a future cost/income can be easily defined for maximum versatility.

Despite the independent nature of individual tables, the columns themselves are horizontally lined up with their more distant siblings, producing a unified singular control for maximum comprehension. By sorting on any column within a category it becomes quickly apparent which entries have the most significant impacts.

Barring visual filtering within and sorting of categories, the interface is locked for editing until explicitly enabled. If the edit-mode is entered, new entries can be added and existing entries can be modified or deleted. Like ways, the financial parameters such as the inflation percentage can be modified. This freedom of interaction is limited to non-aggregated values: manually changing a total would misrepresent its inner structure. Thus, aggregated columns and rows are expressly non-editable.

Upon completion, modifications can be saved or discarded, returning the LCC to the state prior to editing. However, it is not necessary to save the LCC to see the influence of a single change on the greater whole. Upon changing a cell, the modification is input into the model and a recalculation of the row and its hierarchical aggregates is requested. Thus, the result of the change on the model is immediately made visible.

Context

A life-cycle-cost analysis is meaningless without context. This context is realised by intrinsically linking an LCC model with an object. Through this, the RE Suite offers integration between its various facets to provide supplemental data to the LCC model and uses the LCC model to support the decision making process.

Object information such as floor area is similarly imported, preventing calculation errors due to mismatches in redundant data stores. Of course it also facilitates a user-friendly approach as data need only be entered once.

RE Maintenance offers the creation of a multi-year maintenance plan (MYMP) based on condition assessments. This multi-year maintenance plan is directly imported into the LCC

model, integrating real data with predictive projection. The impact of decisions within the LCC on the existing MYMP is represented through a multiplicative factor, e.g. the percentage of expected savings. Thus, an assessment of decision impact can be modelled.
RE Dashboard offers a multi-criteria analysis for decision support. The results of an LCC model are directly imported into the application, offering valuable information for visualisation and integration. Through visualising KPIs based on multiple LCC models representing different decisions RE Dashboard facilitates a comparative analysis.

Based on the provided data the tool creates an overview of the total costs of a building or building stock in the coming 25 years. The period for calculations can be easily adjusted according to the planning. The tool also indicates the RoI in the overview of the costs of renovation as well as provides insight information regarding specific costs, e.g. total operational expenses with separate analysis of maintenance costs and energy consumption.

In the following chapter 3 the results of the preliminary LCC analyses of the chosen demonstration cases are described.

3. Preliminary implementation of LCC analysis in P2ENDURE

3.1 Empirical approach of LCC analysis from real practice

The aim of this deliverable is to find a common approach and validate the methodology for LCC analysis for deep renovation of buildings and to prove possible cost reduction through deep renovation. The following demonstration cases have been chosen for the preliminary implementation of LCC analysis in P2ENDURE due to availability of the cost data before the renovation and an advanced stage of a renovation design:

- Kindergarten in Gdynia, Poland
- Nursery school in Warsaw, Poland
- Nursery school in Genoa, Italy
- Temporary housing in Tilburg, the Netherlands
- Historical residential building in Florence, Italy

In practice several constraints have been approached while gathering the cost data of the demonstration buildings. In case of some of the P2ENDURE renovation projects the cost data before renovation is not anymore available. Hogekamp in Enschede, the Netherlands is one of the examples. The building has been abandoned for several years prior the deep renovation and transformation; therefore, there is no information available on the operational or maintenance costs before renovation. Similar situation emerged in the Florence demonstration case; the provided data is based on energy bills from the times when the building was still operational and on the energy analysis of similar buildings in the region.

Obtaining cost data from the demonstration case in Ancona, Italy is not possible too due to a conflict of the tenants of this social house with the municipality. The occupants are very poor or aged with no willingness in providing information about operational or energy costs or granting permission to make this data available.

LCC analysis will be performed for other demonstration cases if possible / needed when the cost data is available.

In order to gather relevant cost data of the demonstration buildings in a coherent way, an Excel table with listed cost categories needed for the LCC analysis has been sent to the project partners responsible for the demo cases (see Appendix 1).

The operational costs are provided based on carried out audits and gathered bills, e.g. energy or cleaning. The costs of traditional renovation are based on the experience of the renovation, industrial and real estate companies participating in P2ENDURE, like Fasada, Mostostal Warszawa or Camelot Real Estate. The costs of the P2ENDURE solutions are based on the data provided by the partners responsible for the specific solutions, e.g. Fermacell who develops the façade panel or Bergamo Tecnologie who develops the smart window. The estimated percentage of possible energy saving of a P2ENDURE deep renovation strategy is based on the BIM-based energy analysis (description of the methodology and tools for energy analysis are provided in the D3.1 report).
In case of the kindergarten in Gdynia, Poland and the nursery buildings in Warsaw, Poland and Genoa, Italy the revenue is not taken into consideration in the LCCA because of the public , non-profit function of the buildings. This affects the length of the Return on Investment which can be achieved event faster in commercial buildings when the revenue becomes higher after performing deep renovation.

The following examples of the life-cycle cost analyses performed on the real demonstration cases give an overview of the results and provide an indication of possible operational cost reduction by using innovative Plug-and-Play (PnP) technologies for deep renovation in a certain period of time.
Details descriptions of the demonstration buildings and their pre-renovation condition are provided in the D4.1 deliverable report.

3.1.1 Demonstration case in Gdynia, Poland

The demonstration case in Gdynia is a two-storey high kindergarten constructed in 1965. The main goal of the demonstration is to minimize the energy consumption especially for heating needs through the retrofitting of the envelope (add insulation layer), implementing new windows and improve aesthetic appearance of envelope. The building is connected to the district city network.

The kindergarten in Gdynia was the first demo case used for the business case to test the LCC methodology that was described in the chapter 2.1. This building has a total floor net area of 156 m^2 and a total envelope area of 187 m^2. This data is necessary for estimation of costs per m^2, for example of the maintenance costs or the renovations costs of the façade panels.

In this demonstration case, the renovation costs of the proposed P2ENDURE renovation process were approximately estimated to be 15% lower by:

- Cost saving by using innovative PnP components compared to traditional components = -5 %
  Due to higher price of the smart windows and multifunctional prefabricated façade panels
- Cost saving by on-site 3D printing (where applicable) – not applicable
- Cost saving through BIM-based renovation process = 10 %
  Due to more effective and accurate BIM creation based on 3D point cloud achieved from laser scanning, performing BIM-based energy analyses of different renovation strategies
- Cost saving through local factory / district renovation – not applicable
- Cost saving through reduction of failure cost by PnP solutions = 10 %
  Due to using BIM during design and construction stages to improve preciseness of the technical detailing and accuracy of planning

These estimations are approximate as the data on the whole renovation process is not yet available at this stage of the project.

Based on the gathered data (see Appendix 1) cost calculations have been performed for three strategies: maintain-only, traditional renovation and P2ENDURE deep renovation.
In the current situation, when no actions are planned and no costs are incurred for renovation, the maintenance costs will increase drastically: on one hand, because of the autonomous growth of current maintenance costs due to inflation; on the other hand, because of expected additional maintenance due to deterioration of the construction. The same tendency applies to the operational costs, including the costs of energy consumption, in comparison with the traditional and P2ENDURE renovation strategies, as shown below on the Figure 3.

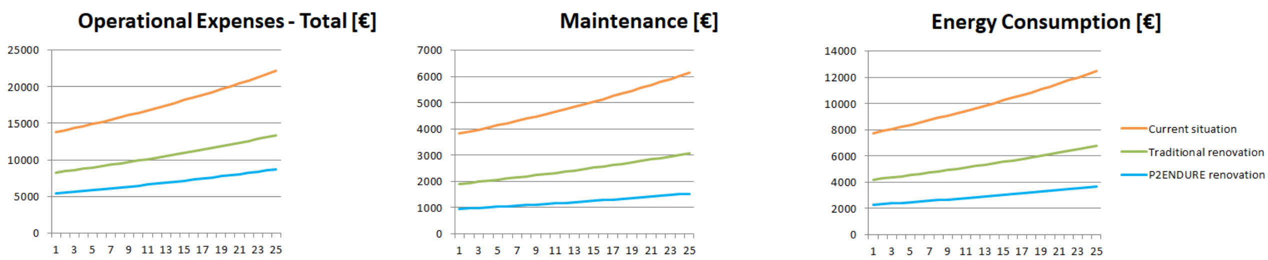


Figure 3: Gdynia demo case: Operational Expenses in three renovation strategies.

The scheme shows that renovation with traditional methods is more beneficial on the longer term than relying on the current maintenance strategy only. This has been calculated by making an inventory of all capital expenses, consisting of renovation costs and related other costs. These costs have a positive impact on the operation expenses in the coming years in comparison to the current situation. The total operational costs, including the maintenance costs and costs for the use of energy would be lower than if no renovation is performed.

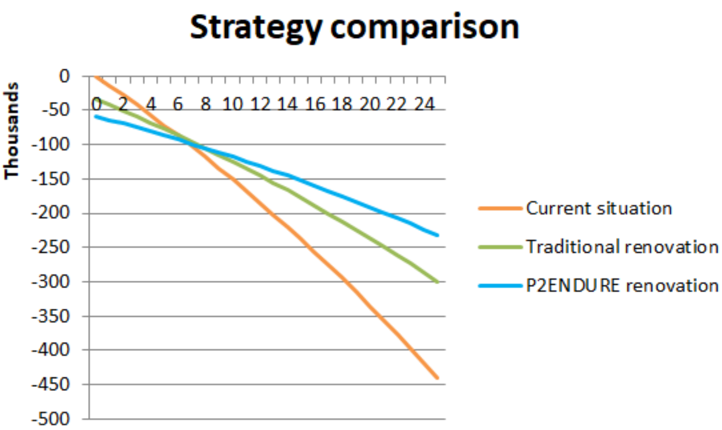


Figure 4: Gdynia demo case: comparison of the three renovation strategies.

Within P2ENDURE, in the Gdynia demonstration case two innovative technologies will be installed that are provided by the project partners who further develop the products to reach TRL8:

- 13 smart windows provided by Bergamo Tecnologie
- FC multifunctional panels provided by Fermacell

The price of the innovative technologies is often higher than of the traditional solutions. Therefore, it may seem on the short term that it is cheaper to take no actions and preserve the current technical condition of the building. However, on the longer term, taking no action is very expensive. In the example of the demonstration case in Gdynia, even though the initial costs of the P2ENDURE renovation are higher, the Return on Investment (RoI) can be achieved in the 7^{th} year (Figure 4). Moreover, the operational expenses after deep renovation in the next 25 years are much lower in comparison to the two other alternatives: maintenance only and traditional renovation (Figure 3).

The benefits of the P2ENDURE renovation are indicated in the costs saving in the following years; taking into consideration the cumulative capital and operational costs of the building the costs will becomes 15% lower in the 9^{th} year and 47% lower in the 25^{th} year after performing deep renovation in comparison with the costs of maintenance of the current situation without renovation.

The proposed P2ENDURE technologies are being still developed within the project, tests on the performance of the solutions are performed and most optimal production method investigated what results in initial higher costs of implementation of these innovative technologies. The costs of the P2ENDURE solutions will become lower when they reach TRL8 and improve their production method to be able to be introduced on the market. This will result in achieving the RoI sooner and improving cost savings more significantly. In P2ENDURE, the performed LCCA have already proved that with innovative technologies the total capital and operational costs can become much lower than in case of traditional maintenance and renovation methods.
With improvement of the P2ENDURE technologies: their TRL and the production method, the price will become lower and therefore, the RoI will be achieved sooner and cost savings will be more significant. The LCCA prove that with innovative technologies the total capital and operational costs can become much lower than in case of traditional maintenance and renovation methods.
The results of the LCCA will be more precise when the energy analyses of different renovation strategies for the kindergarten building in Gdynia are performed. The most cost- and energy-efficient design alternative will be indicated by analysing how different solutions influence the building energy performance (for more information on the methodology and tools for energy analysis check the D3.1 report).

Nowadays, the need to evaluate the life-cycle costs of a project or of investment options becomes more common in public procurement processes across Europe [9]. Public institutions, like the Municipality of Gdynia who is the owner of the kindergarten, have particular requirements for value for money and financial efficiency to be clearly demonstrated in order to invest in construction of new buildings and renovation of existing asset and the use of LCC is an effective means of achieving this.

3.1.2 Demonstration case in Warsaw, Poland

The demonstration case in Warsaw is two-storey high nursery building constructed in 1983 with a total floor net area of 1484 m^2 and a total envelope area of 812 m^2. The main goal of the demonstration is to support Warsaw's climate targets, including energy efficiency, CO2 reduction thanks to the opportunity to test innovative solutions.

The reduction of the renovation costs and LCCA of the demonstration building in Warsaw achieved similar results to the previously described renovation project in Gdynia, Poland due to its similar typology, scale and function (chapter 3.1.1).

In this demonstration case, the renovation costs of the proposed P2ENDURE renovation process were approximately estimated to be 15% lower by:

- Cost saving by using innovative PnP components compared to traditional components = -5 %
  Due to higher price of the smart windows and multifunctional prefabricated façade panels
- Cost saving by on-site 3D printing (where applicable) – not applicable
- Cost saving through BIM-based renovation process = 10 %
  Due to more effective and accurate BIM creation based on 3D point cloud achieved from laser scanning, performing BIM-based energy analyses of different renovation strategies
- Cost saving through local factory / district renovation – not applicable
- Cost saving through reduction of failure cost by PnP solutions = 10 %
  Due to using BIM during design and construction stages to improve preciseness of the technical detailing and accuracy of planning

In the current situation, when no actions are planned and no costs are incurred for renovation, the operational costs (incl. the maintenance costs and the costs of energy consumption) will be increased significantly in the long term in comparison with the traditional and P2ENDURE renovation strategies as shown below on the Figure 5.

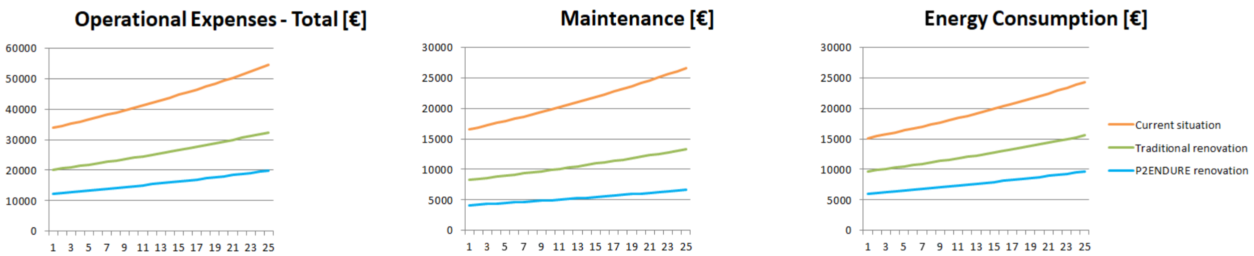


Figure 5: Warsaw demo case: Operational Expenses in three renovation strategies.

The scheme shows that renovation with traditional methods is more beneficial on the longer term than relying on the current maintenance strategy only. The total operational costs, including the maintenance costs and costs for the use of energy would be lower than if no renovation is performed.

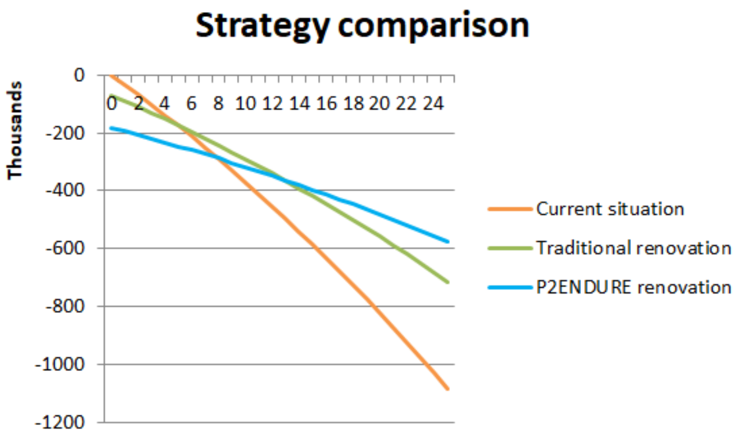


Figure 6: Warsaw demo case: Operational Expenses in three renovation strategies.

The following two P2ENDURE innovative technologies will be installed in the Warsaw nursery building:

- 5 smart windows provided by Bergamo Tecnologie
- FC multifunctional panels provided by Fermacell

In the example of the Warsaw demonstration case, the initial price of the P2ENDURE renovation is higher than the costs of traditional renovation and, the Return on Investment (RoI) can be achieved in the 8th year (Figure 6). The operational expenses after deep renovation in the next 25 years are much lower in comparison to the two other alternatives: maintenance only and traditional renovation (Figure 5).

The benefits of the P2ENDURE renovation are indicated in the costs saving in the following years; taking into consideration the cumulative capital and operational costs of the building the costs will becomes 15% lower in the 10th year and 46% lower in the 25th year after performing deep renovation in comparison with the costs of maintenance of the current situation without renovation.

Similarly to the demonstration case in Gdynia, Poland (chapter 3.1.1), the costs of the proposed P2ENDURE technologies will become lower when they reach TRL8 and improve their production method to be able to be introduced on the market. This will result in achieving the RoI sooner and improving cost savings more significantly. In P2ENDURE, the performed LCCA have already proved that with innovative technologies the total capital and operational costs can become much lower than in case of traditional maintenance and renovation methods.

The results of the LCCA will be more precise when the energy analyses of different renovation strategies for the nursery building in Warsaw are performed (for more information on the methodology and tools for energy analysis check the D3.1 report).

3.1.3 Demonstration case in Genoa, Italy

The demonstration case in Genoa is a nursery school "Nemo" located on the second floor of a two-storey high building constructed in 1930 with a total floor net area of 267 m^2 and a total envelope area of 1077 m^2. The building is listed under the Italian Legislative Decree 42/2004, which poses cultural heritage constraints on its conservation. The goal is to reduce heating consumption through replacement of windows. Additionally, Municipality of Genoa has foreseen heating plant substitution; roof renovation has been performed last year.

Because of the historical status of the Genoa demonstration case, the interventions to choose most energy-efficient renovation strategy are very restricted. Within P2ENDURE, in the "Nemo" nursery building two technologies will be implemented in order to improve energy efficiency of the building:

- 25 smart windows provided by Bergamo Tecnologie. The proposed windows for this demonstration case differ from the ones proposed for the previously described renovation buildings in Poland. The smart windows will be equipped with electromagnetic locks and inflatable gasket system that make the cost higher. Additionally, the window design has been adjusted to the specific esthetical requirements to preserve the historical character of the building
- Cooling system: packaged terminal air-conditioner

In this demonstration case, the renovation costs of the proposed P2ENDURE renovation process were approximately estimated to be 15% lower by:

- Cost saving by using innovative PnP components compared to traditional components = -10 %
  Due to higher price of the smart windows with additional innovative feature and adjusted to the to the specific style of the building to maintain its historical value
- Cost saving by on-site 3D printing (where applicable) – not applicable
- Cost saving through BIM-based renovation process = 15 %
  Due to performing BIM-based energy analyses of different renovation strategies and using BIM to adjust the design of the smart window
- Cost saving through local factory / district renovation – not applicable
- Cost saving through reduction of failure cost by PnP solutions = 10 %
  Due to using BIM during design and construction stages to improve preciseness of the technical detailing and accuracy of planning

The potential energy savings achieved by implementation of the proposed solutions are used for the LCC calculations of the P2ENDURE renovation strategy based on the energy analyses of different renovation alternatives. Detailed description of the methodology and results of the energy analyses are provided in the D3.1 report.

The LCC analyses has shown that the benefits of implementation of the proposed solutions are greater than in the case of traditional renovation and of maintaining the current situation over the years (Figure 7). However, the operational costs are relatively high due to installation of the cooling system that is not nowadays present in the building.

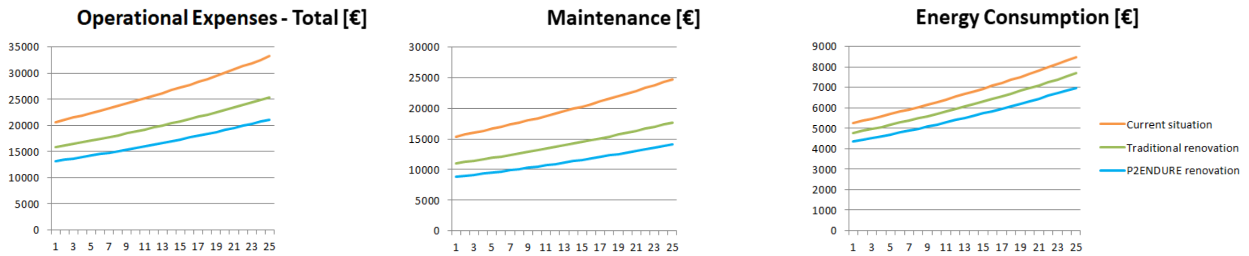


Figure 7: Genoa demo case: Operational Expenses in three renovation strategies.

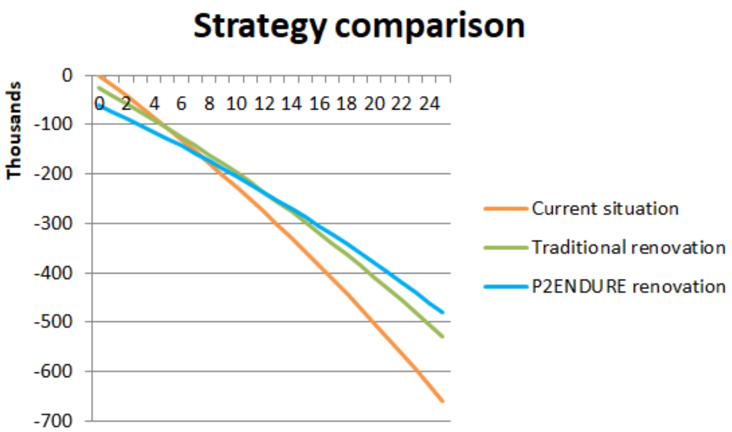


Figure 8: Warsaw demo case: Operational Expenses in three renovation strategies.

Even though, the operational costs become higher because of installation of the air-conditioning, there are several benefits of investing in both smart, energy-efficient windows and good cooling system that are not easy to take into consideration within the LCCA:

- Socio-Economic Benefits there are related to improved internal air quality and comfort.

  Air quality is typically evaluated considering the carbon dioxide (CO2) concentrations. Studies [10] confirm the correlation between the air quality and the performance in schoolwork. When other methods, such as a source control are not available, one way to improve air quality is to increase the rate of outdoor air supply which is guaranteed in this case by the active gasket system of the smart window. The air quality in the classrooms of "Nemo" has been monitored before the renovation and will be monitored again after the installation of the smart windows to evaluate the improvement of the Indoor Environmental Quality (IEQ). The results will be elaborated in the D3.6 report due in February 2020.

  Another studies [11] evaluated the impact of the benefits of the improved air quality on the Gross Domestic Product. The main economic effects are:

  - Reduced teacher sick leave
  - Increased productivity in adult life

  The effect of reduced teacher sick leave can be seen in the short term whereas the increased productivity and personal income in later life is gradually phased in over a ten-year period.

  Other benefits includes the fact that fewer sick days for the youngest children will mean fewer days off work for the parents or caretakers, but little information is available on that in the scientific literature [11].

  In addition controlled natural ventilation is the less expensive strategy to achieve the goal of the air quality improvement if compared to mechanical ventilation or hybrid (mixed mode) [11].

- Tax credit benefits: in Italy a tax credit system is in place for refurbishment activities increasing the energy efficiency of existing buildings such as:

  - reduction of energy demand for heating;
  - improvement of the energy performances of the fabric of the building (insulation, windows)
  - installation of solar panels
  - installation of new heating systems

  Specifically a 50% tax credit (annual bonus for 10 years) scheme is in place according the law n205 27/12/2017 for the procurement and installation of high energy performance windows, such as BGTEC smart windows, after January 1st 2018.

  The scheme is not applicable to public buildings such as "Nemo" nursery school but could be considered in an LCC analysis in case of installation on private buildings.

- Additional exploitation benefits - summer use of the building
  The installation of the BGTEC smart windows is an important step to improve the comfort of the "Nemo" nursery school throughout the year, including the summer season in which, at the moment, the building is not used because of the poor performances of the existing windows and the lack of a cooling system. Given this opportunity the Municipality of Genoa (owner of the building) is studying the possibility to extend the use of the building also during summer for other social activities of the neighbourhood or for a summer school. In order to provide a realistic scenario and evaluating the performances of the smart windows during the summer a cooling system has been included in the LCC analysis scenario.

In the example of the Genoa demonstration case, the initial price of the P2ENDURE renovation is higher than the costs of traditional renovation and the Return on Investment (RoI) can be achieved in the 8th year after the renovation (Figure 8). Even though, the air-conditioning system raises the building energy consumption, the operational expenses after deep renovation in the next 25 years are still lower in comparison to the two other alternatives: maintenance only and traditional renovation (Figure 7). Direct economic payback within the concept of "cost-effectiveness" varies depending on geographical location, for example in Mediterranean regions energy consumption is generally lower than the EU average what makes it more difficult to pay back the interventions in energy saving terms.
In order to estimate the actual life-cycle costs and RoI the abovementioned benefits should be taken into consideration as well. Due to lack of (cost) data on the benefits of using the building in the summer and improving the indoor air quality and comfort, the results of the LCCA in P2ENDURE indicate only the long-term capital and operational costs of the building.

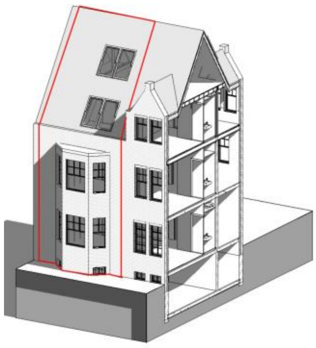
The benefits of the P2ENDURE renovation are indicated in the costs saving in the following years; taking into consideration the cumulative capital and operational costs of the building the costs will becomes 15% lower in the 12th year and 27% lower in the 25th year after performing deep renovation in comparison with the costs of maintenance of the current situation without renovation.

3.1.4 Demonstration case in Tilburg, the Netherlands

The demonstration case in Tilburg is a historical monastery building constructed in 1935 used nowadays as temporary guest accommodation with 60 rooms and with a total floor net area of 4380 m^2 and a total envelope area of 5215 m^2. The goal is to fully renovate the monastery to improve general comfort and energy performance of the building as well as increase flexibility of rental situation. The plan is also to add a bathroom unit to every room, improve ventilation and sound insulation, and insulate windows and the façade.

Deep renovation of this historical building is a complex process due to its monumental status and large scale. The renovation plan has to respect the monumental regulations, which restrict major interventions in the façade and roof area.

The first renovation plans have been created on a pilot area of a vertical segment covering 3 rooms, including partly the cellar and the attic, with a floor net area of 137 m^2 and a total envelope area of 250 m^2 (ca. 3% of the building) as shown on the image of the partial BIM model. Therefore, the preliminary LCC analyses of the renovation design have also been performed on the pilot area. The cost data and renovation plans for the whole building are not yet available at this stage of the project.



Execution of the pilot project gives an opportunity to optimize and demonstrate the P2ENDURE BIM-based renovation process on a smaller scale before applying the strategies for the large-scale deep renovation of the whole building.
The new vertical infrastructure as well as new installations (including a heat pump) group 3 to 6 rooms what allows completing the first stage renovation of the 3 pilot rooms. Performing renovation in several phases will also minimalize the time and number of vacant rooms at once, this will maximize the revenue achieved from renting these rooms, and will prevent the need to provide other temporary residences for the current inhabitants. The regular structure of the building and high repetition of the pilot project creates a realistic approach for estimation of the time, cost and energy savings for the full-scale renovation of the entire building.

In this demonstration case, the renovation costs of the proposed P2ENDURE renovation process were approximately estimated to be 20% lower by:

- Cost saving by using innovative PnP components compared to traditional components = 5%
  Due to lower costs of implementation of the prefabricated bathroom unit
- Cost saving by on-site 3D printing (where applicable) – not applicable
- Cost saving through BIM-based renovation process = 10%
  Due to performing BIM-based energy analyses of different renovation strategies and using BIM during design and construction stages
- Cost saving through local factory / district renovation – not applicable
- Cost saving through reduction of failure cost by PnP solutions = 5%
  Due to using BIM during design and construction stages to improve preciseness of the technical detailing and accuracy of planning

The LCCA of the demonstration building in Tilburg indicated that in the current situation, when no actions are planned and no costs are incurred for renovation, the operational costs (incl. the maintenance costs and the costs of energy consumption) will be increased significantly in the long term in comparison with the traditional and P2ENDURE renovation strategies as shown below in the Figure 9.

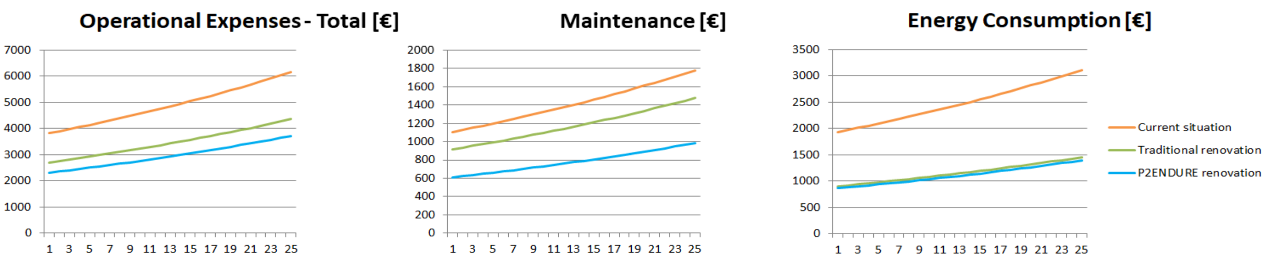


Figure 9: Tilburg demo case: Operational Expenses in three renovation strategies.

The interventions within both traditional and P2ENDURE renovations include installation of new windows, insulation of the walls, floors and the roof, internal wall and floor sound insulation, semi-collective heat pumps, decentralized ventilation and solar panels. The scheme shows that renovation with traditional methods is more beneficial on the longer term than relying on the current maintenance strategy only. The total operational costs, including the maintenance costs and costs for the use of energy would be lower than if no renovation is performed.

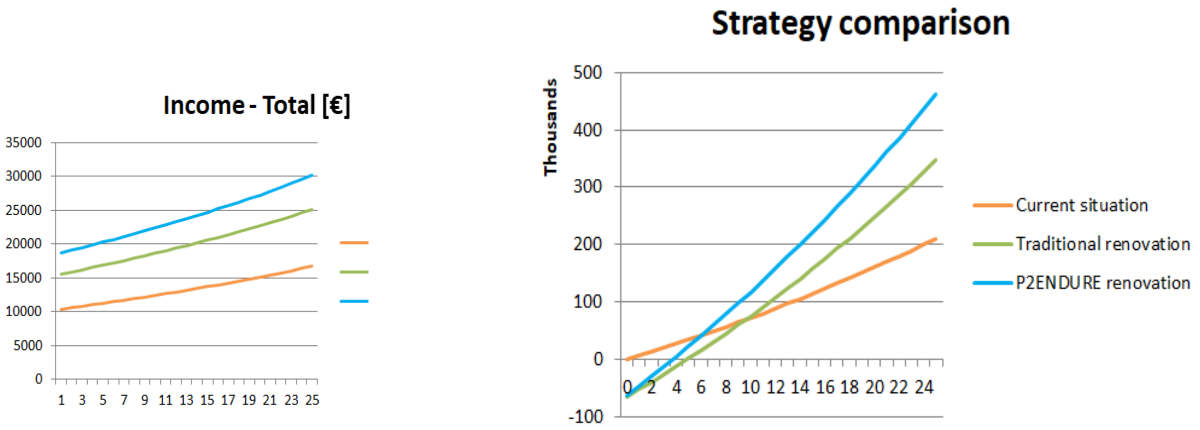


Figure 10: Tilburg demo case: Revenue and Operational Expenses in three renovation strategies.

Within P2ENDURE, PnP prefabricated bathroom units will be installed in every room of the monastery building in Tilburg. By implementation of this innovative technology the price of the P2ENDURE renovation is lower than the costs of traditional renovation of similar scope. Also installation of the proposed bathroom units was estimated to be more than four times cheaper than installation of a new sanitary unit with traditional methods.

The operational expenses after deep renovation in the next 25 years are much lower in comparison to the two other alternatives: maintenance only and traditional renovation (Figure 9).

Moreover, unless the previously described public buildings, improved standard and comfort of the Tilburg demo building due to the deep renovation will benefit additionally from increased revenue of the short-stay rental accommodation.

All the above-mentioned factors have an influence on faster RoI which can be achieved in the 6th year, even though the initial renovation costs are higher than in the previously described demonstration cases.

The benefits of the P2ENDURE renovation are indicated in the profit in long term planning that becomes 15% bigger already in the 7th year and 119% bigger in the 25th year after performing deep renovation taking into consideration the cumulative capital, operational costs and revenue in comparison with the maintenance-only strategy without renovation.

3.1.5 Demonstration case in Florence, Italy

The demonstration case in Florence is a historical building constructed between 1864-1871 for commercial (ground floor and basement) and residential (upper floors) use with a total floor net area of 440 m^2 and a total envelope area of 1095 m^2. The building was standing empty for several years prior the renovation. In the last years a private company has bought the building proposing a new refurbishment project in terms of reuse (new user-needs), improvement of technical condition and energy performance.

The renovation project includes creating an open multifunctional space at the ground floor and six dwellings (about 60 m^2 per dwelling) at the upper floors.

The costs of energy consumption of the current situation are based on the energy bills from the times when the building was still operational and on the energy analysis of similar buildings in the region. The potential energy savings achieved by implementation of the proposed solutions are used for the LCC calculations of the P2ENDURE renovation strategy based on the energy analyses of different renovation alternatives (for more information check the D3.1 deliverable report).

In this demonstration case, the renovation costs of the proposed P2ENDURE renovation process were approximately estimated to be 15% lower by:

- Cost saving by using innovative PnP components compared to traditional components = -5%
  Due to initially higher costs of the innovative solutions
- Cost saving by on-site 3D printing (where applicable) – not applicable
- Cost saving through BIM-based renovation process = 10%
  Due to performing BIM-based energy analyses of different renovation strategies and using BIM during design and construction stages. The BIM will be useful also for the future building maintenance.
- Cost saving through local factory / district renovation – not applicable
- Cost saving through reduction of failure cost by PnP solutions = 10 %
  Due to using BIM during design and construction stages to improve preciseness of the technical detailing and accuracy of planning

The LCCA of the demonstration building in Florence indicated that in the current situation, when no actions are planned and no costs are incurred for renovation, the operational costs (incl. the maintenance costs and the costs of energy consumption) will be increased significantly in the long term in comparison with the traditional and P2ENDURE renovation strategies as shown below in the Figure 11.

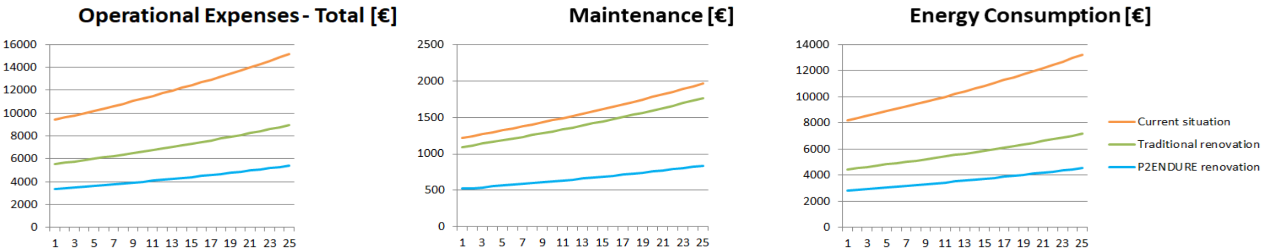


Figure 11: Florence demo case: Operational Expenses in three renovation strategies.

The scheme shows that renovation with traditional methods is more beneficial on the longer term than relying on the current maintenance strategy only. The total operational costs, including the maintenance costs and costs for the use of energy would be lower than if no renovation is performed.

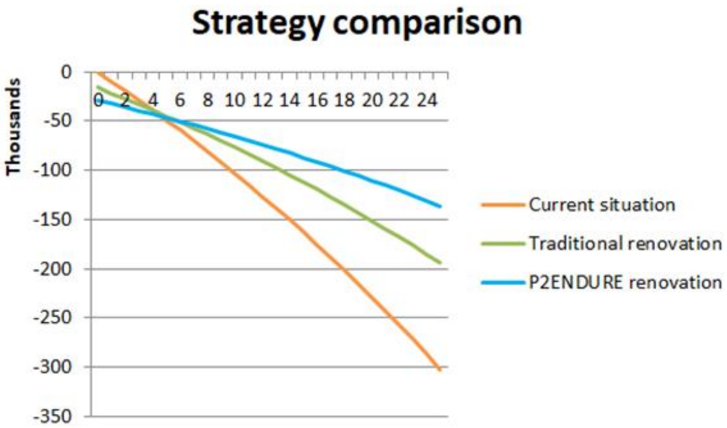


Figure 12: Florence demo case: Operational Expenses in three renovation strategies.

Within P2ENDURE, in the Florence demonstration case two innovative technologies will be installed:

- Roof insulation with high thermal performance with U value= 0,26 (W/m^{2}K)
- 26 windows estimated average Uw value= 1,4 (W/m^{2}K)

In this example, even though the initial costs of the P2ENDURE renovation are higher, the RoI can be achieved in the 5th year (Figure 12). The operational expenses after deep renovation in the next 25 years are much lower in comparison to the two other alternatives: maintenance only and traditional renovation (Figure 11).

The revenue received after the renovation will influence even faster RoI. However, the revenue was not taken into account in the LCC calculations as the data on the revenue of the past situation and predicted scenario after renovation is not yet available. The LCC analyses will be updated when more cost data is available.

The benefits of the P2ENDURE renovation are indicated in the profit in long term planning that becomes 15% bigger already in the 6th year and 55% bigger in the 25th year after performing deep renovation taking into consideration the cumulative capital, operational costs and revenue in comparison with the maintenance-only strategy without renovation.

4. Analysis of time reduction

4.1 Methodology

In order to assess correctly the impact of P2ENDURE solutions on time reduction, the overall renovation process is taken into account. In general renovation process of the building can be divided into five most important stages:

1) **As-built data collection** (P2ENDURE Mapping): This stage covers collection of the information about the actual status of the building in order to create updated building design. In traditional approach to the renovation process as-built data collection is done through the on-site survey and use of rangefinder. Then the 2D CAD drawings showing building cross-sections and façades are developed. This step is especially important for old buildings that have only paper documentation and no 2D CAD documentation. For comparison in P2ENDURE renovation process this stage covers 3D scanning of the building and creation of BIM model based on point cloud point. Also during this stage P2ENDURE approach proposes real-time monitoring of indoor thermal comfort with the use of Comfort Eye devices.
2) **Renovation design** (P2ENDURE Modelling): Depending on the scope of the project, this stage covers different designs that need to be performed in order to make building renovation. The most common areas that tackle during the renovation are: insulation of building envelope (external walls, roof, new windows), new Heating, Ventilation, and Air Conditioning systems, renewables, etc.). Often in traditional approach to renovation before the renovation design will start Energy Audit is performed. Energy Audit describes current energy status of the building and proposes the most common renovation scenarios. Based on the recommendation of the Auditor, and the scope of the renovation given by the Investor, the designers prepare their designs. In case of traditional renovation process, those designs are prepared in a form of 2D CAD drawings and are prepared separately (in different CAD files that are not merged and harmonised). In traditional approach to renovation process (with no BIM model) manual clash detection is performed. This approach allows detecting very limited number of clashes and errors. In comparison in P2ENDURE renovation design stage, the renovation designs are performed in BIM and automatic clash detection take place.
3) **Engineering** (P2ENDURE Modelling): This stage covers energy simulation and development of Building Energy Model. Often in case of traditional renovation energy analysis are limited (or even are not conducted) and the only energy analysis that is

performed is the energy audit (done Renovation design stage). If there is no BIM and the energy analysis still need to be performed, then Building Energy Model is prepared based on 2D CAD drawings. In this step bill of quantities need to be created in order to prepare and start the construction works. During Engineering stage in P2ENDURE approach, BEM model is created semi-automatically and the analysis of different renovation scenarios is performed (e.g. with use of Cypetherm energy simulation tool). After energy simulation renovation design is updated.

4) **Renovation works** (P2ENDURE Making): This step covers all the work that need to be done from the start of the work till commissioning. During traditional approach to renovation works, most of the activities take place on-site and depend on the weather conditions and quality of the construction works performed by blue collar workers. In the traditional approach if the error/collisions appear on the construction site, ad hoc decisions need to be taken. P2ENDURE approach proposes to utilize prefabricated building components and use of BIM to monitor the progress of the construction works. Because clash detection is performed automatically in previous stage, the risk of appearing collisions and errors is much smaller.
5) **Maintenance** (P2ENDURE Monitoring): This step covers maintenance process during building service life. In traditional approach no monitoring process is performed, also maintenance is based on a 2D paper or electrical documentation. P2ENDURE approach proposes to monitor quality of indoor air comfort with Comfort Eyes and use of BIM in asset management.

The techniques and tools used in renovation stages differ slightly by country and by type of the investor.

The goal of P2ENDURE is to prove not only **decrease of the installation time but also decrease of the duration of overall renovation process**. The analysis of duration of renovation process is done for selected demonstration sites:

- Enschede (NL): Vacant building transformed into students resident hall & hotel
- Gdynia (PL): Deep renovation of kindergarten
- Warsaw (PL): Deep renovation of nursery

For those three demonstration sites comparative analysis between: traditional renovation that would be undertaken if the P2ENDURE project would not take place and P2ENDURE renovation process was performed. The duration of the installation works is based on the data gathered during renovation (for Enschede demo site) and simulations (for Gdynia and Warsaw demo case, as those two demo site renovation activities will start in 2019). Traditional process of renovation for all demo sites is done based on the simulations.

Simulations are done based on the experience and internal data of FASADA (Polish SME performing renovation of buildings since 1992), Mostostal (Polish large contractor involve in large renovation projects present on the market since 1945) and Camelot (Dutch investor and building owner).

4.2 Examples

4.2.1 Demonstration site in Enschede, the Netherlands

This demonstration site is a nine-storey abandoned building of the University of Twente located in Enschede, East of the Netherlands. Building was constructed in 1967, the original function of the university building was research and education and was initially designed as a transitory, with the Department of Electrical Engineering and Physics as its first user, and had to be suitable for specific laboratory functions. In order to obtain the required flexibility, the installation shafts and pipes were placed outside the facades. The building was vacant and not used since 2011. The goal of the investor (Camelot and University of Twente) was to transform the building into a student housing (75%) and a hotel (25%). Before the renovation building had G energy label.

The building needed to be renovated till September 2018 because then the academic year starts and the students need to move in. This was a serious constraint and therefore building owner was interested in technologies and solutions that allow faster renovation process. The planned scope of the renovation was to use prefab solutions for the building's envelope, modular prefab bathroom and kitchen units, HVAC systems (Heating, Ventilation and Air Conditioning) and MEP systems (Mechanical Electrical and Plumbing). The goal of the deep renovation was to improve the energy label to at least B (target A).

Figure 13: Enschede demonstration site before renovation.

Nowadays many of the university campus' buildings from the 1960s have been replaced by more modern buildings. Universities across Europe struggle with finding transformation possibilities for these old buildings that are not only energy efficient, but also provide new functional value for the universities. Therefore, the demonstration case in Enschede has large reproduction potential. A similar project is about to start on the TU Eindhoven campus in the Netherlands that could directly benefit from the solutions demonstrated in Enschede.

The construction, including demolition and remediation, has started in April 2017 and has been completed in July 2018. First step was the demolition of non-load bearing elements and removal of asbestos placed in all floors. Asbestos is the name given to a group of naturally-occurring mineral fibres. Asbestos fibres were found to have fire and chemical-resistant properties, so it was adapted and widely used in building materials. However researchers began to find links between asbestos exposure and serious health issues. Asbestos becomes a health risk when its fibres become airborne after it's been disturbed in some way. When inhaled, these fibres can lodge themselves into the lungs, causing scarring and abnormal cell growth, leading to a number of cancers including mesothelioma. Therefore is so important to remove it during the renovation works.

Figure 14: Demolition of non-load bearing building elements and removal of asbestos.

Next step was the assembly of building envelope, rooftop and kitchen/bathroom units. Starting from the 9th (last) floor and proceeding downwards: **40 façade panels and 8 bathroom units were installed per day**.

The installation of prefabricated bathroom and kitchen pods was followed by the installation of plumbing connections. Vertical connecting installations will be performed in a classical way on the spot. Prefabricated bathroom modules were equipped with toilet, shower, bathroom sink and tiles. They were fabricated off-site in the factory in Belgium. Thanks to the prefabrication better quality and aesthetic can be achieved. The use of bathroom modules reduces the amount of work on-site. It also reduced the amount of on-site coordination typically required for multiple trades to work in one area.

Figure 15: Construction of new building envelope from prefab glass-aluminium panels and rooftop.

Figure 16: Assembly of interior partition walls, HVAC and district heat exchanger prefab modules.

Figure 17: Installation of prefabricated bathroom modules and prefabricated doors with frame.

Figure 18: Final appearance of the flat in the student residence hall.

Duration of the P2ENDURE renovation process for Enschede demo building is shown below[1]:

P2ENDURE RENOVATION PROCES

Mapping	Modeling		Making	Monitoring
As-built data collection	**Renovation design**	**Engineering**	**Renovation works**	**Maintanance**
8 weeks	**19 weeks**	**12 weeks**	**60 weeks**	
• Traditional approach to As-built data collection • No use of 3D scanning Use of available 2D documentation in order to create basic BIM model reflecting building before renovation (If needed on-site visits).	• Performance of BIM and selection of renovation prefab product and solutions (incl. MEP&HVAC) and importing them to BIM • Automatic clash detection, **>250 conflicts** between installations (especially HVAC) and structural elements **detected**	• BIM model is automatically converted to BEM Model and edited afterwards (on logical errors) • Performance of energy analysis • Update of renovation design • Automatic generation bill of quantities from BIM model for ordering of the materials	• Using prefabricated components like a complete façade, bathroom, HVAC module, door components with frames makes it easier to compare the different products in relation to their attribution in the project energy saving or time saving • Complete Bathrooms, kitchens, door with frames, facades and city heating components where manufactured off site. The bathrooms saved about 1 week construction work per unit • Use of BIM construction management tool that facilitate reporting, quality and safety check and commissioning	• Automatic reminder about technical inspections • Maintenance based BIM Facility Management

[1] Based on the measured real duration of the renovation process given by Camelot

Simulation of the duration of comparative traditional renovation for the same scope for Enschede demo building is shown below[2].

TRADITIONAL RENOVATION PROCESS SIMULATION

As-built data collection	Renovation design	Engineering	Renovation works	Maintanance
6 weeks	**15 weeks**	**18 weeks**	**138 weeks**	
• No use of 3D scanning • On –site survey and use of available 2D documentation in order to create basic 2D CAD drawings reflecting building before renovation	• No need for energy Audit • Preparation of 2D CAD drawings separately by individual architect and engineers, HVAC experts • Manual checking of possible collisions/errors (comparison of 2D CAD drawings ,high risk of mistake) • Higher chance of finding the errors during renovation works • Exchange of information through emails (risk of not having the final fully updated version of design)	• BEM models have to be implanted / designed by hand based on design or drawings • Energy analysis • Update of 2D CAD design • Manual calculation from 2D drawings of materials and elements need for retrofitting (risk of mistake)	• Preparation of Gantt chart with use MS Project software (Constant manual update) • Detection of conflicts and collisions during construction phase- that provokes delays • Manual quantity survey for mid-payment with subcontractor • No off-site production, all works are made on site • No documentation showing progress of the works • Performance of 2D as-build documentation • Thermal scanning is made after finishing of the works- no possibilities to adjust construction details • Commissioning	• No reminder about technical inspections • Maintenance based on paper and 2D CAD documentations

[2] Simulation is done based on the experience and internal data of FASADA (Polish SME performing renovation of buildings since 1992), Mostostal (Polish large contractor involve in large renovation projects present on the market since 1945) and Camelot (Dutch investor and building owner).

The comparison of two renovation processes is shown in table below. It may be observed that P2ENDURE 4M modular approach allows to achieve around **56% time reduction for construction works and around 44% time reduction of the whole renovation process**. As it may be observed the development of BIM model in renovation design stage takes around 26% more time than the development of 2D CAD renovation design. This was related with the fact the renovation project was very complex and contains designing of many building components and systems. There was no need to performed Energy Audit before the renovation, because the building was not occupied and required deep renovation. Very important aspect is the fact that the use of BIM **allowed to detect more than 250 collisions and errors during design process.** With traditional designing process detection of such high number of collisions would not be possible. This had positive impact on the decrease of the renovation works, as no major collisions and errors were detected during construction works. The decrease in duration of the renovation works is mostly related with the use of prefab solutions for the building's envelope, modular prefab bathroom and kitchen units, HVAC& MEP systems. As built-data collection stage is longer in P2ENDURE approach because the basic BIM model for existing structure was developed. Renovation design phase also was longer for P2ENDURE because designing in BIM requires more time than traditional 2D CAD design. Duration of engineering stage for P2ENDURE approach is shorter (by around 33%) because the energy calculations are performed semi-automatically from the BIM model. In traditional approach BEM model would be performed from 2D Cad drawings and then the energy calculation would be run.

Renovation stages	**Traditional renovation process**	**P2ENDURE 4M modular process**	**Time variation [%]**
	Duration [weeks]	**Duration [weeks]**	
As-built data collection	6	8	+33%
Renovation design	15	19	+26%
Engineering	18	12	-33%
Renovation works	**138**	**60**	**-56%**
TOTAL	177 weeks = 44,25 months	99 weeks = 24,75 months	**44%**

Table 1. Time comparison between traditional and P2ENDURE renovation process for Enschede demo building

4.2.2 Demonstration site in Gdynia, Poland

Demo site in Gdynia (Poland) is a building of a kindergarten no 16 located in a city centre at Jana z Kolna Street 29. It is a two-storey building in the part where the children are staying and one storey in the administrative part, Figure 19. Building was constructed in year 1965 and the kindergarten is attended by around 130 children. Building volume is 2712 m^3 and built up area is 464 m^2. The owner of the building is City of Gdynia. The walls of the building are not insulated (U=1,19 W/m^2K) and in the administrative part there are old wooden windows with U=3,12 W/m^2K). The building is connected to city district heating network.

Figure 19: Photos of the Gdynia demo site before the renovation.

For this building, only old paper documentation from year 1965 was available. Therefore, important part of the project was to perform 3D scanning and develop BIM model than reflects actual building conditions. 3D laser scanning was performed with FARO Focus x130 scanner, the effect of the scanning was a point cloud (see Figure 20) that was post-processed and transform into BIM model. Process of 3D laser scanning was performed within 2 days. Compared to traditional measurements (with the use of rangefinder), it would take around 4 days. 3D scanning process is described in detail in Deliverable D1.5.

Figure 20: Point cloud model obtained from laser scanning process for Gdynia demo case.

The part of the building that will be renovated within the P2ENDURE project is the one-storey administrative part that is shown in Figure 21.

Figure 21: One-storey administrative part of the kindergarten that will be renovated within P2ENDURE project.

Part of the As-built data collection is the installation of Comfort eyes in order to monitor actual indoor air quality. The installation of two Comfort Eyes with associated sensors lasted 2 days (Figure 22).

Figure 22: Installation of Comfort eyes in Gdynia demo site.

The scope of the deep renovation is: insulation of the basement walls (funded and performed by City of Gdynia), insulation of external walls, replacement of old windows, removal of stairs behind the building to the basement (funded and performed by City of Gdynia). **The renovation works will start at 2019, therefore at this moment duration of P2ENDURE renovation works is simulated and will be updated after the demonstration (simulation is done based on the experience and internal data of FASADA).** Stages: As built data collection, Renovation design and Engineering of P2ENDURE renovation process are based on the real time duration measured by FASADA.

First step is the assessment of the P2ENDURE renovation scenario. It is planned to use multifunctional façade panels (developed by Fermacell) that allow for quick installation, horizontal and vertical installation of tubes /ducts. It is also very important that those panels have increased durability. It is planned also to replace 13 old wooden windows with a new simple version of reversible windows (developed by BG TEC). Very important **constraint for renovation of buildings like schools, kindergarten and nurseries** is the fact that the renovation should be performed during the summer holidays, when the children are not attending. **This gives very short time proximately 2-3 month for conduction all the works**. The simulations are done for the renovation of administrative part of the building for façade of 170 m^2 area without windows.

P2ENDURE
PLUG & PLAY BUILDING RENOVATION

P2ENDURE RENOVATION PROCESS

Mapping	Modeling		Making	Monitoring
As-built data collection	**Renovation design**	**Engineering**	**Renovation works**	**Maintanance**
5 weeks	**3 weeks**	**4 weeks**	**6 weeks**	
• 3D scanning • Use of available 2D documentation • Creation of BIM model based on cloud point • Installation of comfort eye for monitoring of the building before renovation	• Performance of BIM with renovation solutions • Automatic clash detection,	• Creation of BEM Model • Performance of energy simulations for the building before renovation and different renovation scenarios • Update of the renovation design after energy simulations • Use of the BIM for automatic generation bill of quantities	• Off-site preparation of substructure for the envelope • On-site activities: installation of wooden substructure, mineral wool and cladding panels • Commissioning with using of BIM • Monitoring with comfort-eye after building renovation	• Digital planning to perform technical inspections with an overview of the building stock • Multi-Year Maintenance Plan based on the RE Suite software tool • Maintenance based BIM Facility Management

Next step is the assessment of the duration of traditional renovation process. This simulation is done base on the experience of FAS (SME performing renovation of the buildings since 1992) and general assumptions/guidelines that the maximum installation of 1m^2 of system based on ETICS (External Thermal Insulation Composite System) takes 120 minutes (1h = 0,5 m^2). This time depends on the weather conditions and the speed of drying of the adhesives. The rule is that the wormer it is the faster renovation with ETICS is going on. For traditional renovation insulation of external walls with 14cm of Expanded Polystyrene for walls above ground and 14cm of Extruded Polystyrene for walls of the basement are assumed.

TRADITIONAL RENOVATION PROCESS SIMULATION

As-built data collection	Renovation design	Engineering	Renovation works	Maintanance
4 weeks	**7 weeks**	**2 weeks**	**12 weeks**	
• On –site survey and use of range finder • Use of available 2D documentation • Preparation of 2D CAD drawings of the building • No monitoring activities	• Performance of Energy audit • Preparation of 2D CAD drawings for renovation • Manual checking of possible collisions/errors (comparison of 2D CAD drawings ,high risk of mistake) • Higher chance of finding the errors during renovation works • Exchange of information through emails (risk of not having the final fully updated version of design)	• No BEM model, only calculation from energy audit are available • Manual calculation from 2D drawings of materials and elements need for retrofitting (risk of mistake)	• Only on-site works, insulation of the walls of basement with extruded polystyrene and walls with ETICS system (expanded polystyrene+ plaster) • The progress of the works depends on the weather conditions, the works can be performed only when temperature >5°C and it is not raining. • No possibility to hide ducts and installations under facade • Performance of 2D as-build documentation • Commissioning	• Manual planning to perform technical inspections regularly • No clear overview of the condition and maintenance plans of the building stock • Maintenance based on paper and 2D CAD documentations

Comparison of duration of two scenarios for renovation is shown in table below. It may be observed that the **P2ENDURE solutions and technologies allow achieving 50% time reduction of construction works**. This is related with the use of partially prefabricated façade panels. As-built data collection stage is 25% longer for P2ENDURE 4M process. This is related with the fact that always performance of design in BIM takes more time than in 2D. The BIM model was developed by the architect who is not experience in BIM modeling, therefore it is expected that the time of BIM modeling can be reduce in future. On the opposite 3D laser scanning process is much faster than traditional on-site survey with the use of range finder. Due to the fact that the demo building is occupied, first step in traditional Renovation design stage is the energy audit process that takes around 4 weeks (in case of Enschede this activity was not needed). This activity also contributes to increase of the duration of traditional renovation process. After having the results of the audit designers prepare 2D designs. In P2ENDURE approach energy calculations are moved to step Engineering and the energy audit in Renovation design is not needed. In traditional approach for Gdynia demo case it is assumed that the BEM model would not be performed, therefore engineering step is shorter in comparison with Enschede demo case for which the BEM model in traditional renovation process would be performed. T**he decrease of the duration of whole renovation process is around 28%.**

Renovation stages	Traditional renovation process	P2ENDURE 4M modular process	Time variation [%]
	Duration [weeks]	Duration [weeks]	
As-built data collection	4	5	+25%
Renovation design	7	3	-57%
Engineering	2	4	+100%
Renovation works	**12**	**6**	**- 50%**
TOTAL	25 weeks = 6,25 months	18 weeks = 4,5 months	**-28%**

Table 2: Time comparison between traditional and P2ENDURE renovation process for Gdynia demo building

FASADA with PAN+ performed also renovation design related to adding rooftop module on the administrative part of the building, Figure 23. In this manner, the area of the kindergarten can be increased without the need for building up new land. The design will be passed to the City of Gdynia, after termination of the P2ENDURE project City of Gdynia will make the decision about the potential funding of the rooftop extension.

Figure 23: Visualisation of adding rooftop module for Gdynia demo building.

PAN + has already designed and monitor the installation process of “traditional” rooftop module for the building in Tilburg (NL). The experience gathered during that renovation works will be a basis for estimation of installation time for P2NDURE and traditional rooftop retrofit module for Gdynia demo site.

Step of renovation works		Duration of traditional installation process of rooftop extension																												
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Organisation of construction site																														
1	Organisation of construction site																													
Structural works																														
2	Adapting of dwelling structure and additional foundations or foundation reinforcement (optional)																													
3	Placing of steel construction floor addition																													
4	Placing of the new pipes under construction																													
5	Placing of walls (wood skeleton)																													
6	Placing roof and finishing																													
Inside finishing works																														
7	Placing of installations																													
8	Placing ducts and infrastructure																													
9	Floor finishing																													
10	Finishing of walls and ceiling																													
11	Electric finishing works and setting up installations																													
12	Painting works																													
	Total duration	29 weeks = 7,25 months																												

Step of renovation works		Duration of installation of P2ENDURE rooftop retrofit module																										
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Organisation of construction site																												
1	Organisation of construction site	■																										
Structural works																												
2	Adapting of dwelling structure and additional foundations or foundation reinforcement (optional)		■	■																								
3	Placing of steel construction floor addition				■																							
4	Placing of the new pipes under construction																											
5	Placing of walls (prefabricated steel elements)						■	■																				
6	Placing roof and finishing								■	■																		
Inside finishing works																												
7	Placing of installations					■																						
8	Placing ducts and infrastructure									■																		
9	Floor finishing										■																	
10	Finishing of walls and ceiling											■																
11	Electric finishing works and setting up installations													■														
12	Painting works												■															
Total duration		13 weeks = 3,25 months																										

As it can be observed the installation time of P2ENDURE rooftop retrofit module is **55% less than a traditional comparable technology**. The execution time on site is reduced substantially. Production of steel frame constructions is very precise; no measurement flaws will be detected. Working through a BIM model ordering products is efficient and errors are substantially reduced. Use of steel frame construction allows also for reduction of waste material in production process (production-demand). The rooftop construction of steel frame is produced in 2D façade and floor components. All holes for ducts are already placed in the steel structure. The frame is finished with the first layer of external painting, insulation and vapour foil.

4.2.3 Demonstration case in Warsaw, Poland

The building was built in 1983 and is one of 55 municipal nurseries in Warsaw, Poland (see Figure 24). It is a place for temporary care to 108 children aged 1-3 (6 groups). Building volume is 5,525 m^3 and built up area is 631 m^2. The owner of the building is City of Warsaw. The building is connected to city district heating network. The building is made of prefabricated concrete elements and cellular concrete wall and comprises two over ground floors and one floor in the basement. The approximate value of thermal transmittance factor U=1,2 [W/m^2K] and for the windows U=1,5 and 5.1 [W/m^2K].

Figure 24: Photos of the Warsaw demo site before the renovation.

For this building, only old paper documentation was available (see Figure 25). Therefore, like for Gdynia demo building important part of the project was to perform 3D scanning (see Figure 26) and develop BIM model that reflects actual building conditions.

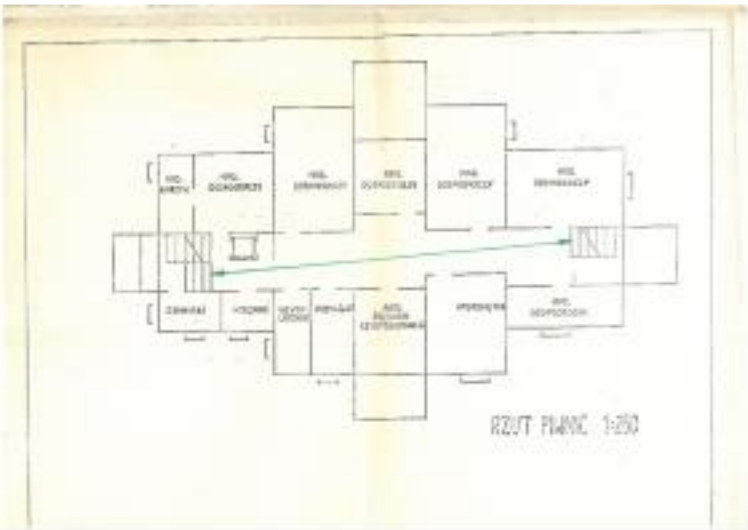


Figure 25: Old paper documentation.

The FARO Focus3D scanner was used for the 3D scanning process for Warsaw demo cases (see Figure 26). The weight of the scanner is around five kilograms. The Focus3D laser scanner is suitable for mobile use on the building site. The scan both for the inside and outside of the building was carried out only for 2 days. Compared to traditional measurements (with the use of rangefinder), it would take around 5 days. The purpose of the scan was to make a precise inventory of the 3D points (see Figure 27). 3D scanning process is described in detail in Deliverable D1.5.

Figure 26: 3D Scanning process of Warsaw demo site.

Figure 27: Point cloud model obtained from laser scanning process for Warsaw demo case.

The entire modelling process of the general construction part of the nursery facility took 27 working days (around 5, 5 weeks). The model was created at the level of detail LOD300, to consist of the most accurate geometry of the object based on the point cloud, together with the parameters of the materials used and their heat transmittance. The detailed information about the spent time with the division of tasks during modelling is presented in the graph below (see Figure 28).

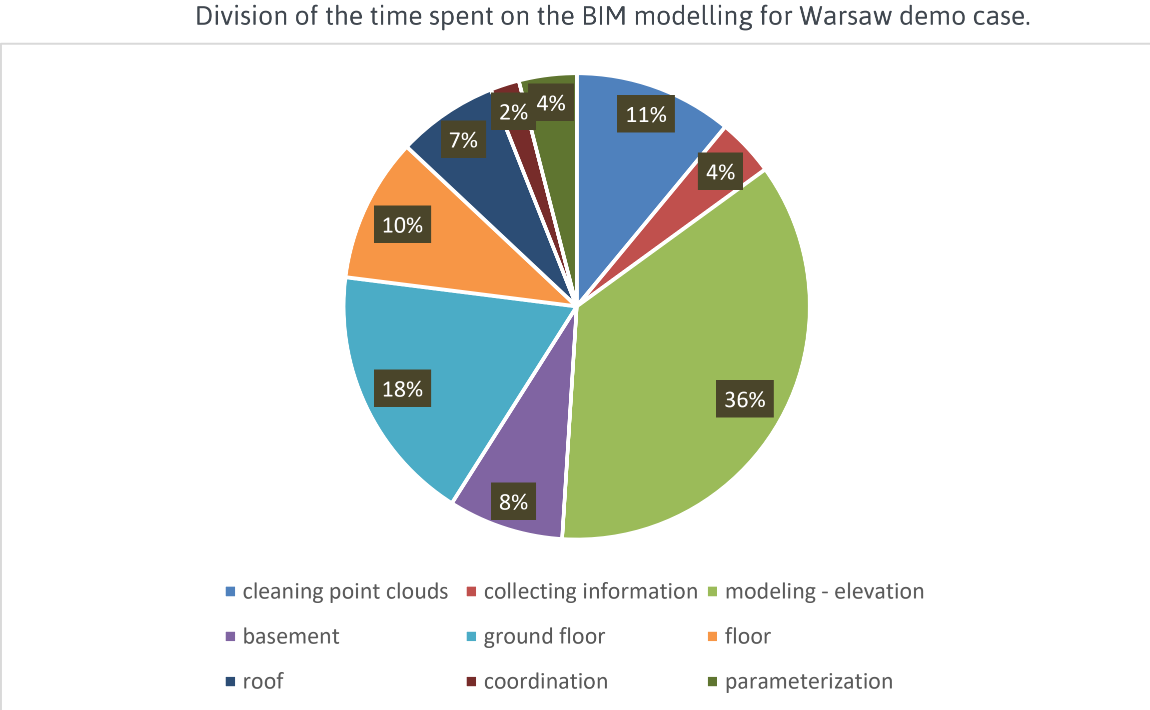


Figure 28: Time spent on modelling divided into percentages.

Part of the As-built data collection is the installation of Comfort Eyes in order to monitor actual indoor air quality. The installation of four comfort eyes with associated sensors last 2 days, see Figure 29.

Figure 29: Installation of Comfort eyes in Warsaw demo site.

The scope of the deep renovation is: insulation of the basement walls (funded and performed by City of Warsaw), insulation of external walls (with multifunctional façade panels developed by Fermacell) and replacement of old window (5 reversible BG TEC windows funded by P2ENDURE project and new commercial PCV windows funded by City of Warsaw). Having BIM models created on the basis of a point cloud and families of objects of new renovation products, it is easier to locate collisions (see Figure 30) at the stage of creating an executive design project. In the case of a demonstration building in Warsaw, thanks to BIM model, it is easy to notice that the windows in the corners will have to be reduced because only then, the new prefabricated facade panels could fit in.

Figure 30: On the left: collision between an existing window and a new facade panel. On the right: design proposal to reduce the size of a window in order to find space for a facade panel.

The renovation works will start at 2019, therefore at this moment both renovation scenarios: P2ENDURE and traditional renovation are based on simulation and will be updated after demonstration. If the nursery is not closed, it is important to perform most of the renovation works during July and August, when the children are not attending to the building. The area of the intervention on the building facade is around 650m^2 (without windows area).

First, simulation of the duration of planned P2ENDURE renovation scenario is performed. Duration of As-built data collection and Renovation design is performed on the real duration of the process measured by Mostostal. Duration of Renovation works is simulated based on the experience and internal data of FASADA (Polish SME performing renovation of buildings since 1992) and Mostostal (Polish large contractor involve in large renovation projects present on the market since 1945).

P2ENDURE RENOVATION PROCESS

Mapping	Modeling		Making	Monitoring
As-built data collection	**Renovation design**	**Engineering**	**Renovation works**	**Maintanance**
6 weeks	**5 weeks**	**8 weeks**	**12 weeks**	
• 3D scanning • Use of available 2D documentation • Creation of BIM model based on cloud point • Installation of comfort eye for monitoring of the building before renovation	• Performance of BIM with renovation solutions • Automatic clash detection,	• Creation of BEM Model • Performance of energy simulations for the building before renovation and different renovation scenarios • Update of BIM renovation design • Use of the BIM for automatic generation bill of quantities	• Off-site preparation of substructure for the envelope • On-site activities: installation of wooden substructure, mineral wool and cladding panels • Commissioning with using of BIM • Monitoring with comfort-eye after building renovation	• Automatic reminder about technical inspections • Maintenance based BIM Facility Management

Below simulation of traditional renovation process is presented. This simulation is performed based on the experience and internal data of FASADA (Polish SME performing renovation of buildings since 1992) and Mostostal (Polish large contractor involve in large renovation projects present on the market since 1945). For this scenario it is assumed that exterior walls are insulated with expanded polystyrene or rock wool (with a conduction coefficient of λ= 0.040 W/(m*K)), with a 15 cm-thick insulation layer (ETICS system). It is assumed also that the exterior walls of the basements (above ground level and up to 1 m below ground level) will be insulated with a 10-cm thick insulation layer (extruded polystyrene with a conduction coefficient of λ = 0.035 W/(m*K)).

TRADITIONAL RENOVATION PROCESS SIMULATION

As-built data collection	Renovation design	Engineering	Renovation works	Maintanance
5 weeks	**10 weeks**	**3 weeks**	**25 weeks**	
• On –site survey and use of range finder • Use of available 2D documentation • Preparation of 2D CAD drawings of the building • No monitoring activities	• Performance of Energy audit • Preparation of 2D CAD drawings for renovation • Manual checking of possible collisions/errors (comparison of 2D CAD drawings, high risk of mistake) • Higher chance of finding the errors during renovation works • Exchange of information through emails (risk of not having the final fully updated version of design)	• No BEM model, only calculation from energy audit are available • Manual calculation from 2D drawings of materials and elements need for retrofitting (risk of mistake)	• Only on-site works, insulation of the walls of basement with extruded polystyrene and walls with ETICS system (expanded polystyrene/minera l wool+ plaster) • The progress of the works depends on the weather conditions, the works can be performed only when temperature >5°C and it is not raining. • No possibility to hide ducts and installations under facade • Performance of 2D as-build documentation • Commissioning	• No reminder about technical inspections • Maintenance based on paper and 2D CAD documentations

Comparison of duration of two scenarios for renovation is shown in table below. It may be observed that the **P2ENDURE solutions and technologies allow achieving 52% time reduction of construction works**. D**uration of whole renovation process is decreased by around 27%.** This value is lower in comparison with Enschede demo case, this is related with the fact the renovation of Warsaw demo site consists of adding insulation of the façade and new windows. Such type of intervention requires relatively simple 2D CAD design (similar as for Gdynia demo building). The situation is different for more complicated renovation, where different systems and solutions are applied (e.g. Enschede demo site). For Warsaw demo case (the same as for Gdynia demo building) Renovation design stage in traditional renovation process consists of performance firstly energy audit (around 4 weeks) and then development of 2D designs with final renovation scenario. Building Energy Model is not performed for traditional renovation process, therefore there is an increase in Engineering stage by 166%. It need to be added that traditional solution for façade renovation (ETICS) is definitely less durable during the service life and requires more maintenance works than faced panels developed by Fermacell.

Renovation stages	Traditional renovation process	P2ENDURE 4M modular process	Time variation [%]
	Duration [weeks]	Duration [weeks]	
As-built data collection	5	6	+20%
Renovation design	10	5	-50%
Engineering	3	8	+166%
Renovation works	**25**	**12**	**-52%**
TOTAL	43 weeks = 10,75 months	31 weeks = 8 months	**-27%**

Table 3: Time comparison between traditional and P2ENDURE renovation process for Warsaw demo building

MOSTOSTAL with PAN+ performed also renovation design related to adding rooftop module on the roof of the building, Figure 31Figure 23. In this manner, the area of the nursery can be increased without the need for building up new land. The design will be passed to the City of Warsaw, after termination of the P2ENDURE project City of Warsaw will make the decision about the potential funding of the rooftop extension.

Figure 31: Visualisation of adding rooftop module for Warsaw demo building.

5. Conclusions and recommendations

Using Plug-and-Play prefabricated solutions has a significant impact on the design, construction and operational phase. Such components give better insight in the energy analysis and enable to choose the most efficient solution. This saves time and costs and simplifies the decision-making process. Due to the fact that prefabricated products are engineered already there is just a very small chance of occurring designing errors. The BIM clash detection also allows saving construction time and increases the quality of the construction. Moreover, this approach contributes to cost reduction and reduction of design errors. It may be observed that P2ENDURE approach allows **decreasing the duration of overall renovation process between 25-44%**. It may be concluded that the more complex the renovation is the higher reduction of the P2ENDURE overall renovation process is obtained. However **it need to be highlighted that the decrease and increase of the duration of the different stages of renovation process strongly depends on the building type, scope of the renovation and national requirements and building practice.** This is true especially for the Renovation design and Engineering stage.

The duration of installation works in all demo cases is decreased by 50% up to 56%. For Gdynia and Warsaw demo sites the simulated duration of P2ENDURE installation works will be verified and compered with real duration. Decrease of the installation time is crucial aspect for buildings as schools, kindergarten or nurseries in which renovation works can be performed only during short time as holidays and the works cannot affect the working process of the institution.

Another very important aspect is that the prefabrication allows using lower number of workers on the construction site and they can have lower qualifications. This can be observed on the example of prefabricated modular bathroom and kitchen units that are delivered to the building site already with tiles and some interior finishing. This issue plays important role now, when in Europe there are large problems with availability of blue collar workers in construction. With prefabrication constructors are less dependent on weather circumstances while the quality is guaranteed. In the operational and maintenance phase it is easier to exchange components but also to monitor deviations. All products need to be the same quality, so anomalies normally should be found in assembly errors.

In the coming years the number of mayor retrofitting projects needs to be increased in order to meet the 20-20-20 EU energy efficiency targets in the building sector. Performing life-cycle cost analyses (LCCA) helps building owners and asset managers to understand the financial benefits and opportunities that can be achieved with deep renovation and can make it possible to improve the energy performance of buildings considerably.

The life-cycle costs (LCC) over the life of a building or building stock are widely acknowledged as a good indicator of value for money than the initial acquisition / construction costs alone.

For example, the costs of owning and occupying an office building over a 30 year period are typically in the broad ratio of 1 (construction costs) to 5 (maintenance costs) to 200 (cost of the operations being carried out in the building, including staffing costs) [9]. Therefore, creating a reliable overview of the maintenance and operational costs of assets, rather than on capital costs alone, can bring significant long-term financial and environmental benefits.

LCCA provides also an economic evaluation of alternative design options indicating different capital, operating costs or resource usage. In P2ENDURE, performing LCCA in an early design stage provided a review of a project frame and its objectives. On the example of the five demonstration cases, first estimations of the capital and operational expenses of different renovation alternatives were provided giving a chance to the developers / architects / engineers either to adjust the proposed renovation strategies or to choose the most cost-efficient one. The earlier in the concept phase the life-cycle costs can be indicated and taken into consideration for the renovation design, the more effectively the LCC performance of a building can be maximized.

P2ENDURE is a research project where the new technology are being tested and further developed to reach TRL 8. The materials and production technology may not be fully advanced yet at the time of implementation of these solutions in the demonstration cases. This can results in higher costs of renovation of the demonstration cases. The costs of the P2ENDURE solutions will become lower when they reach TRL8 and improve their production method to be able to be introduced on the market. This will result in achieving the RoI sooner and improving cost savings more significantly. In P2ENDURE, the performed LCCA have already proved that with innovative technologies the total capital and operational costs can become much lower than in case of traditional renovation and maintenance methods.

Moreover, improvement of the BIM-based renovation process to create most energy- and cost-efficient design strategy based on energy calculations and LCCA will smoothen the design and construction stage, improve communication between different parties and, in result, reduce costs of construction failures through high-precision on-site processes and self-inspection during the renovation process. This has been addressed in another Horizon2020 project titled INSITER where techniques for BIM-based self-instruction and self-inspection were developed.

Also, the results of the LCCA will be more precise when the energy analyses of different renovation strategies for some of the demonstration buildings will be performed. The most cost- and energy-efficient design alternative will be indicated by analysing how different solutions influence the building energy performance (for more information on the methodology and tools for energy analysis check the D3.1 report).

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APPENDIX 1 – Cost data of the chosen demo cases

Cost data of the demonstration case in Gdynia, Poland

Input Data for LCC

General information		
Name	Gdynia demo case: Przedszkole nr 16	
Function	*Kindergarten*	
Country	*0.72*	*Automatic Index for PL*
Year of construction	1965	
Condition score	4	*1 (excellent) - 6 (very bad)*
Surface/net area	*156*	m2
Envelope surface	*187.3*	m2 (including doors and windows)

For ETICS assesment of costs

CAPEX				
Renovation costs:	**P2E Deep renovation - FC facade panels [€/m2]**	**P2E Deep renovation BG windows (13 windows)**	**Traditional renovation - ETICS system (14cm of EPS+plaster [€/m2]**	**Traditional renovation Timber Windows with U=0,9 (price for 13 windows)**
New products	*110*	9100 [700 €/window]	*70*	5000
Materials	*70*	7628.4	*29*	4460
Installation	*40*	500	*29*	540

OTHER costs:	€		€	*Total amount*
Transport	€		€	*(break-down of other costs - optional)*
Disposal/removal	€		€	*(break-down of other costs - optional)*
Other (please name)	€		€	*(break-down of other costs - optional)*
Capex %	*% (if payed in instalments)*	*% (if payed in instalmen*	*(optional)*	

OPEX		*costs per year*		
	Current situation	**P2E Deep renovation**	**Traditional renovation**	
Maintenance	€	€	€	*Total amount*
Facade	*20*	5	*10*	*€/m2 per year*
			energy reduction with traditional renovation is 49,02% based on energy audit	
Energy consumption	€	€		*Total amount*
Heating	6,831.70 €	€	€	*€/per year - data from 2016*
Electricity	621.50 €	€	€	*(break-down of total energy costs - optional)*
Other (please name)	€	€	€	*(break-down of total energy costs - optional)*
OTHER operational costs	€	€	€	*Total amount*
Water	1,487.83 €	€	€	*€/per year - data from 2016*
Rental costs	0.00 €	€	€	*(break-down of other operational costs - optional)*
Other (sewage)	619.00 €	€	€	*(break-down of other operational costs - optional)*

Revenue		*costs per year*	**Gdynia demo building is a public kindergarten with no revenue**
	Current situation		
Room rent	€		
Restaurant	€		
Conference centre	€		
Nursery/kinderkarten	€		
Subsidy	€		
Other (please name)	€		

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Cost data of the demonstration case in Warsaw, Poland

Input Data for LCC

General information		
Name	Warsaw demo case: Nursery nr 3	
Function	*Nursery*	
Country	*Poland*	
Year of construction	1983	
Surface/net area	*1484*	*m2*
Envelope surface	*812.26*	*m2 (including doors and windows)*

CAPEX		costs of the renovation			
Renovation costs:	**Product 1 - traditional (Insulation with External Thermal Insulation Composite System (ETICS) based on expanded polystyrene boards and painted thin layer plaster)**	**Product 1 - innovative (P2ENDURE)**	**Product 2 - traditional (plastic frame five-chamber window with a two-pane package, U≤ 1.1 W / m2**	**Product 2 - innovative (P2ENDURE)**	
New products	*55 €/m2*	110 €/m2	*130 - 175 €/m2*	1600 €/window	
Materials		75 €/m2			
Installation	*29 €/m2*	40 €/m2	540 €	not known	
OTHER costs:	€	€	€	€	*Total amount*
Transport	€	€	€	€	*(break-down of other costs - optional)*
Disposal/removal	€	€	€	€	*(break-down of other costs - optional)*
Other (please name)	€	€	€	€	*(break-down of other costs - optional)*
Capex % (if payed in instalments)	*% and no. of years*	*% and no. of years*	*% and no. of years*	*% and no. of years*	*(optional)*
					(% of interest rate and number of years to pay back)

OPEX		*costs per year*		
	Current situation, data 2016	**P2E Deep renovation**	**Traditional renovation**	
Maintenance	**€**	***€ or % of reduction***	***€ or % of reduction***	*Total amount*
Building component 1	*20*	*5*	*10*	*€/m2 or % of reduction per year*
Building component 2	€	*€ or %*	*€ or %*	*€/m2 or % of reduction per year*
Energy consumption	*€ 14,530*	***€ or % of reduction***	***€ or % of reduction***	*Total amount*
Heating	*€ 10,769*	*at least 60%*	*45,4% according to Energy Audit 2015*	*€/m2 or % of reduction per year*
Electricity	*€ 3,367*	*€ or %*	*€ or %*	*(break-down of total energy costs - optional)*
Other (please name)	*€ 394*	*€ or %*	*€ or %*	*(break-down of total energy costs - optional)*
OTHER operational costs	**€**	***€ or % of reduction***	***€ or % of reduction***	*Total amount*
Water	€	*€ or %*	*€ or %*	*€/m2 or % of reduction per year*
Rental costs	€	*€ or %*	*€ or %*	*(break-down of other operational costs - optional)*
Other (sewage)	€	*€ or %*	*€ or %*	*(break-down of other operational costs - optional)*

Revenue		*costs per year*	***Warsaw demo building is a public nursery with no revenue***
	Current situation		
Room rent	€		
Restaurant	€		
Conference centre	€		
Nursery/kinderkarten	€		
Subsidy	€		
Other (please specify)	€		

Cost data of the demonstration case in Genoa, Italy

Input Data for LCC

General information	
Name	Genoa demo case: Via Cialli nr 9
Function	*Kindergarten*
Country	*Italy*
Year of construction	1932
Surface/net area	*267* *m2*
Envelope surface	*1077* *m2 (including doors and windows)*

CAPEX	costs of the renovation			
Renovation costs:	**Double glass windows (compliant with the national requirements) -**	**BGTech smart windows (25)**	**Product 2 - traditional**	**Product 2 - innovative (P2ENDURE)**	
New products	*17098*	60830	*25280*		
Materials					
Installation					
OTHER costs:	€	€	€	€	*Total amount*
Transport	€	€	€	€	*(break-down of other costs - optional)*
Disposal/removal	€	€	€	€	*(break-down of other costs - optional)*
Other (please name)	€	€	€	€	*(break-down of other costs - optional)*
Capex % (if payed in instalments	*% and no. of years*	*% and no. of years*	*% and no. of years*	*% and no. of y*	*(optional)*
				(% of interest rate and number of years to pay back)	

OPEX	*costs per X years*			
	Current situation	**P2E Deep renovation**	**Traditional renovation**	
Maintenance	*14 (€/m2y)*	8 €/(m2 y)	*10 €/(m2 y)*	*Total amount*
Windows	*€ and frequency*	*€ or % and frequency*	*€ or % and frequency*	*€/m2 or % of reduction per X years + frequency*
			energy reduction with traditional renovation is 15% based on benchmark	
Energy consumption	**€**	**€ or % of reduction**	**€ or % of reduction**	*Total amount*
Heating	*2,878 €*	*2,206.60 €*	*15%*	*€/m2 or % of reduction per year*
Electricity (exluded cooling)	*1,314 €*	*1,314 €*	*1,314 €*	*(break-down of total energy costs - optional)*
Cooling	*862 €*	*656 €*	*€ 832*	*(break-down of total energy costs - optional)*
OTHER operational costs	**€**	**€ or % of reduction**	**€ or % of reduction**	*Total amount*
Water	€	€ or %	€ or %	*€/m2 or % of reduction per year*
Rental costs	€	€ or %	€ or %	*(break-down of other operational costs - optional)*
Other (sewage)	€	€ or %	€ or %	*(break-down of other operational costs - optional)*

Revenue	*costs per year*	***GENOA demo building is a public kinderkarten with no revenue***
	Current situation	
Room rent	€	
Restaurant	€	
Conference centre	€	
Nursery/kinderkarten	€	
Subsidy	€	
Other (please specify)	€	

Cost data of the demonstration case in Tilburg, the Netherlands

Input Data for LCC

General information		
Name	Lidwina Monastry	
Function	*lodging house*	
Country	*Netherlands*	
Year of construction	1935	
Condition score	3	*1 (excellent) - 6 (very bad)*
Surface/net area - full project	*4380*	*m2*
Envelope surface - full project	*5215*	*m2 (including doors and windows)*
amount of rooms	*59*	
Surface/net area - pilot	*137*	*m2*
Envelope surface - pilot	*250*	*m2 (including doors and windows)*
amount of rooms - pilot	*3*	

CAPEX		*costs of the renovation*	*per pilotproject (3 rooms)*		
Renovation costs:	**Sanitairy unit - traditional**	**Sanitairy unit - innovative (P2ENDURE)**	**Estimation other products traditional**	**Total investment (P2ENDURE)**	**Total investment traditional**
New products	€ 12,400.00	€ 10,800.00	€ 78,000.00	€ 88,800.00	€ 90,400.00
Materials	*€ 8,400.00*	*€ 9,900.00*			
Installation	*€ 4,000.00*	*€ 900.00*			
OTHER costs:	€	€	€	€	€
Transport	€	€	€	€	€
Disposal/removal	€	€	€	€	€
Other (please name)	€	€	€	€	€
Capex % (if payed in instalments)	*% and no. of years*	*% and no. of years*	*% and no. of years*	*(optional - % of interest rate and number of years to pay back)*	

OPEX	Current situation	P2E Deep renovation (*costs per year*)	Traditional renovation (*per pilotproject (3 rooms)*)
Maintenance	*€/year*	*€/year*	*€/year*
Sanitairy (unit)	€ 200.00	€ 100	€ 200.00
distribution (sewage/ water)	€ 310.00	€ 50	€ 150.00
installations	€ 194.00	€ 300	€ 400.00
windows	€ 170.00	€ 50	€ 50.00
building envelope (excl windows)	€ 210.00	€ 100	€ 100.00
	€ 1,084.00	€ 600	€ 900.00
Energy consumption	*€/year*	*€/year*	*€/year*
Heating	€ 1,260.00	€ 0.00	€ 0.00
Electricity	€ 600.00	€ 835	€ 870.00
Other (please name)	€	€ or %	
OTHER operational costs	*€/year*	*€/year*	*€/year*
Water	€ 500.00	€ 700	€ 700.00
Rental costs	€ 250.00	€ 100	€ 150.00
Other (sewage)	€	€ or %	

Revenue	Current situation	P2E Deep renovation (*revenue per year*)	Traditional renovation (*per pilotproject (3 rooms)*)
Room rent	€ 10,000.00	€ 18,000.00	€ 15,000.00
Restaurant	€		
Conference centre	€		
Nursery/kinderkarten	€		
Subsidy	€		
Other (please specify)	€		

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Cost data of the demonstration case in Florence, Italy

General information		
Name	Florence demo case	
Function	Residential and commercial	
Country	Italy	
Year of construction	1864-1871	
Surface/net area	439.8	m2
Envelope surface	1094.9	m2 (including doors and windows)

CAPEX		costs of the renovation		
	Product 1 - traditional roof insulation with U value= 0,35 (W/mqK)	**Product 1 - innovative** P2ENDURE roof insulation with high thermal performanca with U value= 0,20 (W/mqK)	**Product 2 - traditional** 26 windows estimated average Uw value= 1,9 (W/mqK)	**Product 2 - innovative** P2ENDURE 26 windows estimated average Uw value= 1,4 (W/mqK)
Renovation costs: New products Materials Installation incl. other costs, e.g. transport cost	€ 6,328.35	€ 8,099.70	€ 9,680.00	€ 20,901.00
OTHER costs:	€	€	€	€
Transport	€	€	€	€
Disposal/removal	€	€	€	€
Other (please name)	€	€	€	€
Capex % (if payed in instalments	% and no. of years	% and no. of years	% and no. of years	% and no. of years

OPEX		estimated costs per 1 years		
	Current situation	P2E Deep renovation	Traditional renovation	
Maintenance	€/y	€/y or % of reduction	€/y or % of reduction	Total amount
Roof	613 €/y	490€/y (20% of reduction)	490€/y (20% of reduction)	
Windows	584 €/y	266€/y (64% of reduction)	584€/y (21% of reduction)	
Energy consumption	€	% of reduction	% of reduction	Total amount
Heating, DHW €/m2	0.00	60.18%	45.69%	€/m2 or % of reduction per year
Heating, DHW €/year	0.00			
Electricity				(break-down of total energy costs - optional)
Other (please write)				(break-down of total energy costs - optional)
OTHER operational costs	€	€ or % of reduction	€ or % of reduction	Total amount
Water	€	€ or %	€ or %	€/m2 or % of reduction per year
Rental costs	€	€ or %	€ or %	(break-down of other operational costs - optional)
Other (sewage)	€	€ or %	€ or %	(break-down of other operational costs - optional)

Revenue	costs per year
	Current situation
Room rent	€
Restaurant	€
Conference centre	€
Nursery/kinderkarten	€
Subsidy	€
Other (please specify)	€